"SCREENING AND SELECTION OF EFFICIENT VESICULAR ARBUSCULAR MYCORRHIZAE (VAM) FOR AONLA (*Emblica officinalis* Gaertn)."

Thesis

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In

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By

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JHANSI-284 003 (UP)

2007

Dedicated

To

My

Late

Grand

Parents

And

My

Beloved

Parents

Declaration

I hereby declare that the thesis entitled "**Screening and Selection of Efficient Vesicular Arbuscular Mycorrhizae (VAM) for Aonla (*Emblica officinalis* Gaertn).**" *being submitted for degree of* ***Doctor of Philosophy*** *to the Department of Botany, Bundelkhand University, Jhansi (UP) is an original piece of work done by me under the supervision and guidance of* ***Dr. Anil Kumar, Senior Scientist, NRCAF, Jhansi*** *and to the best of my knowledge, any part or whole of this thesis has not been submitted for a degree or any other qualification of any university or examinee body in India/ elsewhere.*

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Certificate

*This is to certify that the work embodied in this thesis entitled "***Screening and Selection of Efficient Vesicular Arbuscular Mycorrhizae (VAM) for Aonla (*Emblica officinalis* Gaertn).***"* being *submitted by **Ms. Shahnashi Hashmi,** for the award of **degree of Doctor of Philosophy** to the Bundelkhand University, Jhansi, has been carried out under my supervision and guidance, that the work, embodied has not been submitted elsewhere for the award of any other degree and is up to the mark both in its academic content and the quality of presentation.*

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July, 2007

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Introduction

INTRODUCTION

Aonla (*Emblica officinalis* Gaertn.) is an important minor fruit crop of Indian origin. It can be grown in salt affected soils with high pH and poor fertility of semi-arid regions. It occupies an area of 20,000 ha with production of two- lakh metric tons and productivity of 15-20 t ha^{-1} (Pathak, 2000). Aonla is widely grown in Uttar Pradesh, Maharashtra, Gujarat, Haryana, Punjab, Tamilnadu, Andhra Pradesh and Karnataka, wherein Uttar Pradesh alone contributes for 60% production. Aonla fruits have special significance due to their high nutritive value and rich medicinal properties. It is a rich source of vitamin-C and is widely used in Unani and Ayurvedic systems of medicine. Aonla fruits are utilized for processing several value-added products like preserves and pickles. It is also an important ingredient of Chyavanprash, Trifla, Amla ki Rasayan and powder, which are good for diabetic patients.

Plant roots provide an ecological niche for many of the microorganisms that abound in soil. German Botanist A.B. Frank (1885) introduced the Greek word *mycorrhiza* to scientific terminology, which literally means "fungus root". In natural ecosystems much of the root system can be colonized by mycorrhizal fungi. Colonization is restricted to the root cortex and does not enter the vascular cylinder. The symbiosis is so well balanced that, although many of the host cells are invaded by the fungal endophyte, there is no visible tissue damage and under certain conditions it enhances the growth and vigor of the host plant. Because most economically important plants form mycorrhizae, the subject is currently attracting much attention in agricultural, horticultural and forestry research. Three general types of mycorrhizal associations have been recognized:

- Vesicular arbuscular mycorrhizae (VAM)
- Ectomycorrhizae (ECM)
- Ericoid or ectendo-mycorrhizae

Over a long period of time, specific climate and edaphic factors have been responsible for the selection of the distinctive types of mycorrhizae being associated with defined vegetation types. Species with ericoid mycorrhizae are predominantly present in soil of high altitudes and latitude, ecto-mycorrhizae species predominant in forest ecosystem of intermediate altitudes and latitudes and plants with VAM dominate herbaceous and woody plant communities on mineral soils at low latitudes (Read, 1991). Present study consisted of VAM fungi of Aonla and some other minor fruits due to their common occurrence in Bundelkhand region.

Mycorrhizae have received considerable attention in recent years because mycorrhizal plants have several advantages over non-mycorrhizal plants. Mycorrhizal associations are generally considered to benefit host plants by enhancing mineral nutrient acquisition, especially with regard to phosphorus, which is relatively immobile in the soil. Mycorrhizal fungi have also been found to enhance water transport in plants (Safir *et.al.*, 1971), decrease transplant injury (Menge *et.al.*, 1978), promote establishment of plants in wasteland and reduce the vulnerability to diseases caused by soil borne pathogens (Schonbeck, 1979). As already mentioned Aonla is hardy in nature and gaining popularity for utilizing marginal and degraded lands in arid and semi-arid regions of our country. Screening and selection of efficient VAM species for Aonla will provide suitable mycorrhizal strains to obtain better quality plants. It is expected that more economic returns to the extent of 20-30% will be available to the target groups, without any significant increase in input cost. Therefore, the present study was taken up with broad objective to identify suitable vesicular arbuscular mycorrhizal (VAM) species for Aonla and some other minor fruits viz., Ber (*Zizyphus mauritiana* Lamk.), Chironji (*Buchanania lanzan* Spr.) and Lasoda (*Cordia myxa* Roxb.). To achieve this, following specific objectives were set:

Objectives:

- Identification of sites with good mycorrhizal plants in local orchards and nurseries.
- Identification of VAM species, which occur in abundance at identified sites.
- Studies on relationship between soil parameters and VAM species at marked sites.
- Culturing of common VAM species.
- Screening of VAM species for vigorous plant growth under nursery conditions.

Review Of Literature

REVIEW OF LITERATURE

Plant roots provide an ecological niche for many of the microorganisms that abound in soil. German Botanist A.B. Frank (1885) introduced the Greek word *mycorrhiza,* which literally means "fungus root," In natural ecosystems much of the root system can be colonized by mycorrhizal fungi. Colonization is restricted to the root cortex and does not enter the vascular cylinder. The symbiosis is so well balanced that, although many of the host cells are invaded by the fungal endophyte, there is no visible tissue damage and under certain conditions it enhances the growth and vigor of the host plant. Because most economically important plants form mycorrhizae, the subject is currently attracting much attention in agricultural, horticultural, and forestry research. There are different types of mycorrhizae. The main types of mycorrhizae and the host plants in which they are commonly associated are given in Table 2.1. As the present study was concerned with vesicular arbuscular mycorrhizae (VAM), information available in literature on its benefits, occurrence, taxonomy, ecology and culturing techniques was reviewed and is being presented here, in short.

Table 2.1 Different types of mycorrhizae and their hosts

Types of Mycorrhizae	Host plant/families
Ecto	Pinaceae, Fagaceae, Betulaceae, Leguminaceae, mostly caesalpinoid legumes, Salicaceae, Tiliaceae, Rosaceae, Juglandaceae, etc.
Vesicular arbuscular	Majority of the plants including those important in agriculture, horticulture, pasture and tropical forests
Ericoid	Ericaceae and Epacridaceae
Orchidaceous	Orchidaceae
Arbutoid	Arbutus and Monotropha

2.1 Benefits of VAM Fungi

VAM fungi confer following benefits on the host:

- Enhance acquisition of mineral nutrients, especially phosphorus, which is relatively immobile in the soil.
- Enhance water transport in plants, decrease transplant injury and promote establishment of plants in wasteland. Mycorrhizal plants recover better following moisture stress, more efficient in water use and frequently have higher root-shoot ratio than non-mycorrhizal plants.
- Reduce the vulnerability to diseases caused by soil borne pathogens.
- Increase plant growth by 20-30% in terms of bio-mass.
- Enable the plants to grow and survive better under various stress conditions, like those in coal spoils, sand dunes, saline-alkaline soils, eroded- degraded sites and lands polluted by industrial wastes.

2.2 Occurrence

VAM fungi have the widest host range and distribution of all the mycorrhizal associations. It is estimated that about 90% of vascular plants normally establish mutualistic relationship with VAM fungi. VAM fungi have been observed in 1000 genera of plants representing some 200 families. There are at least 300,000 receptive hosts in the world flora (Kendrick and Berch, 1985), and there are about 120 species of VAM fungi (Schenck and Perez, 1987). If the hosts are divided up evenly among the fungi with no overlap in host range, each fungus would have more than 2500 potential partners. We know that host ranges overlap extensively, suggesting that some individual VAM fungi may well have access to thousands of hosts (Kendrick and Berch, 1985).

According to Gerdemann (1975), it is easier to list most plant families that do not form vesicular arbuscular fungi than to list those that do. Families not forming Vesicular arbuscular fungi include Pinaceae, Betulaceae, Orchidaceae, Fumariaceae, Commelinaceae, Urticaceae, and Ericaceae.

Families that rarely form arbuscular mycorrhiza include the Brassicaceae, Chenopodiaceae, Polygonaceae, and Cyperaceae. Families that form both ectomycorrhizae and vesicular arbuscular fungi include Juglandiaceae, Tilliaceae, Myrtaceae, Salicaceae, Fagaceae, and Caesalpiniaceae (Gerdemann, 1975). Important crops with vesicular arbuscular fungi include wheat, maize, all millets, potatoes, beans, soybeans, tomatoes, apples, oranges, grapes, banana, castor, tobacco, tea, coffee, cocoa, sugarcane, mango, asparagus, rubber, cardamom, pepper, etc. Most of the tropical rain forest trees are vesicular arbuscular mycorrhizal (Janos, 1983). Harley (1969) has listed the gymnosperms in which vesicular arbuscular mycorrhizae have been observed. They are found in Pteridophytes (Cooper, 1976) and Bryophytes (Parke and Linderman, 1980). Recently, vesicular arbuscular mycorrhizal colonization has been reported in floating (Bagyaraj *et al.*, 1979) and submerged aquatic plants (Clayton and Bagyaraj, 1984). Usually vesicular arbuscular mycorrhizae are confined to the roots; they have been reported in diverse structures such as the modified leaves of water fern *Salvinia cucullata* (Bagyaraj *et al.*, 1979), fruiting peg of peanut (Graw and Rehm, 1977) and modified scale like leaves and rhizomes of ginger and canna (Selvaraj *et al.*, 1986).

Vesicular arbuscular mycorrhizae, in addition to their widespread distribution throughout the plant kingdom, are also geographically ubiquitous and occur in plants growing in arctic, temperate, and tropical regions (Mosse *et al.*, 1981). In general, VAM population is more in cultivated soil compared to virgin soil (Mosse and Bowen, 1968). They are mostly seen in the top 15-30 cm of soil, and their numbers decrease markedly below the top 15 cm (Redhead, 1977). They are normally not found in depths beyond the normal root range of plants (Mosse *et al.*, 1981). The distribution of species of VAM fungi varies with climatic and edaphic environment as well as with land use. For example *Acaulospora laevis* is common in Western Australia (Abbott and Robson, 1977) and New Zealand (Mosse and Bowen, 1968) but occurs less

frequently in soils of Eastern Australia (Mosse and Bowen, 1968). *Glomus* species appear to have widest distribution. *Gigaspora* and *Sclerocystis* species are more common in tropical soils. *Acaulospora* seems to be better adapted to soils with pH <5.0. In fact, certain VAM fungi have been linked to particular kinds of soil: *Glomus mosseae* with fine textured, fertile, high pH soils; *Acaulospora leavis* with coarse-textured, acid soils; and *Gigaspora* species with sand dune soils (Kendrick and Berch, 1985).

2.3 Taxonomy

VAM fungi, being obligate biotrophs, do not grow on synthetic media and hence are classified according to morphological characteristics of the spores formed in the soil. One hundred and twenty species have been described by Schenck and Perez (1987), and they are all grouped in a single family, the Endogonaceae. The family is considered to be in an order of its own, the Endogonales tentatively placed in the class Zygomycetes in the subdivision Zygomycotina (Benjamin, 1979). The seven genera, *Endogone, Glomus, Sclerocystis, Entrophospora, Acaulospora, Scutellospora and Gigaspora,* presently constitute the Endogonaceae. Of these, only *Endogone* forms zygospores characteristic of Zygomycetes, while others probably lack sexual reproduction, species of *Endogone* do not form vesicular arbuscular mycorrhizal association. The other six genera form vesicular arbuscular mycorrhizal associations.

The main features of VAM fungi are summarized by Trappe and Schenck (1982) and Hall (1984). Hall and Abbott (1983) compiled photographic transparencies illustrating diagnostic features of the Endogonaceae. Walker (1983) has suggested a standardized terminology for use in description of endogonaceous spore walls involving a stylized graphic representation of the wall structure ("murograph"). This concept is recommended for future descriptions of new species. Recently, Schenck and Perez (1987) published a manual for the identification of VAM fungi.

Glomus, the most common genus of VAM fungi, has over 50 species which form globose, ellipsoid or rather irregularly shaped spores that range from 20-400 µm. These spores are thick-walled (up to 30 µm), and hyaline, yellow, red-brown, brown or black. Spores are attached to a single subtending hypha (or to two, three, or more in exceptional species) and produced in the soil near plant roots, at the soil surface, or occasionally in roots, and they may form singly, in groups of a few to many, or in large aggregates called sporocarps. Sporocarps are most commonly found in undisturbed forest communities with perennial plants and accumulated organic material. Sporocarpic species, when grown on plants in pot culture, usually produce spores singly or in small aggregates. Some *Glomus* species (e.g., *Glomus lacteum*) are not known to form spores in sporocarps, while others form spores outside the plant root only infrequently (e.g., *Glomus intraradices*). The spores of most species germinate by emergence of a germ tube directly through the subtending hypha.

Sclerocystis species produce chlamydospores that are very similar to those of *Glomus*, except that they tend to be clavate rather than globose. All *sclerocystis* species form spores only in sporocarps up to 700 µm in diameter. The spores, which can be up to 125 µm long, develop in a single layer, radially arranged around a central plexus of sterile and sporogenous hyphae. The sporocarps may group together in masses up to several cm in diameter on the soil surface, on leaves, twigs, and mosses. There is no published information on the germination of *Sclerocystis* spores.

Spores of the genus *Acaulospora* appear to form laterally on the neck of a small thin-walled saccule, called variously a mother spore, a vesicle, a hyphal terminus, a soporiferous saccule, or a sporogenous saccule (Walker, 1987). When mature, the spore does not display a subtending hypha because the vesicular structure that gives rise to it loses its cytoplasm and collapses during development of the spore. The spores are globose or ellipsoid, from <100 to >400 µm in diameter, and hyaline, yellow, or reddish-brown. The

surface of the sporewall may be ornamented with pits, projections of various shapes, folds, spines, or reticulations, and the wall is up to 12 µm thick. One species of *Acaulospora* is now known to produce sporocarps, but in other species, spores are normally found in the soil of the rhizosphere, *Entrophospora* is more or less similar to *Acaulospora* except that the spore is formed inside the parent hypha just below the vesicle.

Scutellospora spores can be greater than 600 µm in diameter, and the smallest ones are just under 200 µm in diameter. Spores develop terminally on a bulbous hyphal suspensor, which remains attached at maturity and may bear short lateral projections. Spores are usually globose but can be ovoid, obovoid, pyriform, or irregular. Spores are hyaline, white, yellow, pinkish, grey-green, or brown. Spore wall structure is composed of at least two wall groups, with one or more flexible membranous or coriaceous walls in the inner group or groups. The genus is characterized in particular by its mode of spore germination. Germination is by means of one or more germ tubes produced near the spore base from a germination shield formed within or upon a flexible inner wall. Thin walled, knobby, or broadly papillate auxiliary cells (vesicles) are borne in soil on straight or coiled hyphae, formed singly or in clusters. *Gigaspora* produces spores which are superficially similar to those of *Scutellospora* spores. The striking differences are the germination of spores, which is by direct growth of one or more germ tubes through the spore wall. It is possible that this genus evolved from *Scutellospora* (Walker, 1987).

Another fungus, or group of fungi, that forms endomycorrhizae has been referred to in the literature as "the fine endophyte," since its hyphae are <4 um wide, compared to 10-20 µm for typical VAM fungi. This anomalous endophyte has been described as *Glomus tenue*, though it does not resemble the other species of *Glomus*. Its spores are 10-15 µm in diameter, and when young are hyaline and indistinguishable from the vesicles that form in the roots; when mature, however, they are pigmented. Because of their small size as compared to those of other VAM fungi, the spores of *Glomus tenue* are not

often recorded in nature, though mycorrhizae of this type are common, particularly in dry regions.

2.4 Factors Affecting the Development of Mycorrhizae

A. Physical Factors:

***Temperature*:** Temperature has been shown to have a significant influence on colonization and sporulation by VAM fungi under greenhouse conditions. Higher temperatures generally result in greater root colonization and increased sporulation (Furlan and Fortin, 1973). Studying the effects of temperature on VAM establishment, Schenck and Schroder (1974) observed that maximum arbuscule development occurred near 30°C but that mycelial colonization of the root surface was greatest between 28 and 34° C. Daniels and Trappe (1980) observed that optimum temperature for the germination of *Glomus* and *Acaulospora* spores is around 20-25°C, whereas *Gigaspora* had a much higher optima. These studies suggest that increased soil temperature hastens the development of VAM fungi. This may explain the slow development of infection in agricultural crops in temperate soils (Black and Tinker, 1979) where soil temperatures are low compared to tropical soils. Since most species of VAM fungi exist worldwide, it is possible that strains and species may be temperature adapted. This is suggested by the work of Schenck *et al.* (1975), who found that two isolates of *Glomus* from Florida germinated best at 34°C, whereas one from Washington had an optimum of 20°C.

***Light*:** VAM fungi obtain their carbon source from the host plant and thus rely on both the photosynthetic ability of the plant and the translocation of photosynthates to the root. Hence, light can strongly affect the development of mycorrhizae. The stimulatory effect of light on the development of vesicular arbuscular mycorrhizae has been shown by Furlan and Fortin (1977). Shading not only reduces root colonization and spore production but also the plant response to VAM fungi (Gerdemann, 1968). Redhead (1975) postulated that day length may play an important role in vesicular arbuscular mycorrhizal development, and this was confirmed by Daft and El-Giahmi (1978).

However, the effect of light on VAM fungi seems to depend on the photosensitivity of the species of host plant (Redhead, 1975). In fact, a photoperiod of 12 hour or more may be more important than light intensity in providing high levels of root colonization, but if suitable day length is provided, increased light intensity may still increase colonization (Daft and El-Giahmi, 1978). It could be particularly interesting to examine this aspect in plantation crops like coffee, cardamom, etc., which are cultivated under shade trees in the tropics.

Water: A continual decline of germination of *Gigaspora gigantea* in polyethylene glycol from 80% at – 0 MPa to 15% at –10 MPa was reported by Wilson (1984). *Glomus caledonicum, Gigaspora calospora and Acaulospora laevis* spores showed high germination from –0 to 1.4 MPa, but delayed germination at –2.2 MPa (Tommerup, 1983). These data suggest that more spore germination can probably occur at soil moisture levels at which roots do not normally grow (Bowen, 1984).

VAM fungi occur over a wide range of soil water contents. Colonization has been found in arid regions in xerophytes (Khan, 1974), very wet soils of marshes (Dowding, 1959), and also in free-floating (Bagyaraj *et al.,* 1979) and submerged aquatic plants (Clayton and Bagyaraj, 1984). It was believed earlier that under saturated conditions, O_2 concentration can inhibit VAM spore germination and root colonization (Saif, 1981). Le Tacon *et al.* (1983) observed for spores germinated in air that their subsequent growth was little affected by lack of O_2 until the oxygen tension was below 3%. The recent observations on mycorrhizae in aquatic plants suggest that perhaps in water there is adequate dissolved O_2, and concentrations of toxic substances such as Mn, H_2S, organic acids, etc., developing under anaerobic conditions are probably absent. Soil water may select for certain species of VAM fungi, which adapt to that environment (Manjunath *et al.,* 1981).

B. Chemical factors:

***pH*:** Studies conducted in the laboratory on agar media suggest that good germination of VAM spore occurs between pH 6 and 7, although there are cases of fungi germinating at pH 5 and below as well as pH 8 and above (Sparling and Tinker, 1978). Optima for germination of *Gigaspora corraloidea, Gigaspora heterogama,* and *Glomus mosseae* on the agar have been recorded at pH 5, 6 and 7, respectively (Green *et al.,* 1976).

In soil, effects of pH are difficult to evaluate since many chemical properties of soil vary with changes in pH. In soil, more than 40% germination of *Glomus epigeum* spores was found over the pH range 4.8-8.0, the optimum being 7.2 (Daniels and Trappe, 1980). Sparling and Tinker (1978) found no obvious effect of pH on infection in three grassland sites at pH 4.9, 5.9 and 6.2, however, such infection may have been due to different endophyte species. There is some evidence for differences in adaptation of strains and species of VAM fungi to pH. Lambert and Cole (1980) reported that six isolates of *Glomus tenue* differed in their ability to form mycorrhizae at low pH. Daft *et al.* (1975) reported considerable VAM colonization in plants growing in a bituminous mine spoil of pH 2.7. Natural soils of the world cover the pH range 2.8 to >10.0 (Bas Becking *et al.,* 1960). Soil pH may affect the distribution of mycorrhizae in a subtle way.

***Phosphorus*:** The addition of phosphorus affects VAM colonization of roots (Jasper *et al.,* 1979 and Menge *et al.,* 1978). Conclusive recommendations for specific soil P levels for mycorrhizal production cannot be made. There are several reasons for this. First, it is not soil P per se that regulates mycorrhizal colonization, but rather the amount of P absorbed by the host plant (Menge *et al.,* 1978). Second, methods for evaluating available soil P often differ greatly, and plant tissue analysis is a far more reliable method for determining available soil P than most methods that analyze soil. Finally, since host plants vary in their ability to absorb P and mycorrhizal fungi vary in their response to P, each plant – soil – VAM symbiont system must be evaluated separately

(Jasper *et al.,* 1979 and Menge *et al.,* 1978). For example, in one sandy soil, maximum spore production by *Glomus fasciculatum* on sour orange occurred at 50 ppm added P, but this amount of P applied to a different citrus variety (*Troyer citrange*) did not encourage sporulation (Menge *et al.,* 1978).

Tissue P is also not always a good estimate for mycorrhizal colonization because the mycorrhizae themselves influences that factor. It is thought that P influences VAM colonization by affecting concentrations of root carbohydrates (Jasper *et al.,* 1979) or the amount of root exudates (Graham *et al.,* 1981) and for that reason the effects of P concentration may be partially overcome by other factors such as light intensity (Graham *et al.,* 1982). The best indicator for identifying a soil that will provide good VAM colonization appears to be the percentage of P in plants at the time of VAM colonization (Jasper *et al.,* 1979). Recently, Sreenivasa and Bagyaraj (1989) observed that rock phosphate applied at 100 ppm P level resulted in more of infective propagules of *Glomus fasciculatum* compared to bone meal and superphosphate fertilizers (Clarke, 1981). Long-term application of superphosphate fertilizer (15 years of 150 kg P/ha/yr) was found to result in a population of VAM endophytes that was little affected by subsequent additions of P (Porter *et al.,* 1978). It appeared that P-tolerant strains have developed during the 15-year period of superphosphate application. More work in isolating P-tolerant strains is needed, as they can be used for inoculating high-yielding varieties of field crops and horticultural crops demanding application of heavy doses of fertilizers.

Nitrogen: Hayman (1975) showed that N fertilizers (188 kg N/ha as Nitro-chalk) had a large negative effect on the mycorrhizal population. This was confirmed later by Jensen and Jakobsen (1980). Alexander and Fairley (1983) reported reduction in mycorrhizal colonization following application of 300kg N/ha as $(NH_4)_2\ SO_4$. Davis and Young (1985) reported NO_3^- salts to be more inhibitory to VAM development than NH^+_4 salts. These results indicate that

nitrogen contents of soils could greatly influence the distribution and abundance of VAM fungi.

***Micronutrients*:** Micronutrients such as manganese (Mn) and zinc (Zn) inhibit spore germination of mycorrhizal fungi (Hepper, 1979). Zinc and copper (Cu) was shown to inhibit mycorrhizal colonization in clover, onion, maize, soybean and pinto bean (Mosse *et al.* 1981 and Ponnamperuma, 1972). Zinc, copper and manganese applied at the rate of 12, 2, 5 and 40 ppm, respectively, along with Ruakura solution improved mycorrhizal root colonization, sporulation and the most probable number of infective propagules of *Glomus fasciculatum* (Sreenivasa and Bagyaraj, 1988).

Acid soils contain much soluble Al, Mn and Fe and in neutral soils Mn and Fe can be released in large quantities when reducing conditions prevail after waterlogging (Ponnamperuma, 1972). Many soils are grossly polluted with heavy reclaimed site of an old lead mine at Shipham, England and found considerable colonization in white clover growing on soil heavily contaminated with Zn and Cd. This suggests that VAM endophytes can develop strains adapted to particular soil conditions. Hence, one of the prime strategies for reclamation of mine tailings should be the selection, introduction and maintenance of suitable mycorrhizal fungi.

***Pesticides*:** Trappe *et al.*, (1984) have reviewed the effect of pesticides on mycorrhizal fungi and mycorrhizae. Most research with pesticides has been undertaken with soil fumigants, fungicides and nematicides which exhibit a range of activity towards VAM fungi. Fumigation of soil with biocides such as Methyl bromide, Chloropierin, Formaldehyde, Mylone, Vapam and Vorlex effectively kill endophytes in the treatment zone. Fortunately, these fungi reinvade most fumigated soils within several years. Unlike the general biocides, most nematicides such as 1, 3-dichloropene (1,3-D), 1,2-dibromoethane (EDB), 1,2-dibromo-3-chloropropane (DBCP) and some of the organophosphates (Bhenomiphos) and organocarbamates (Aldicarb) at recommended rates exhibit no or a slight inhibitory effect. Interestingly, some

nematicides, such as DBCP and 1,3-D, can stimulate root infection in host plants. This type of response is believed to be due to control of competitive and plant-pathogenic microflora, to possible stimulation of exudates from host plant roots or to other factors.

The systemic fungicides like Thiobendazole, Benomyl and Triadimefon are more toxic to these fungi. Pentachloronitrobenzene, which is not systemic, is also highly toxic. Many fungicides are probably only fungistatic to these fungi (Nemec, 1987). Limited research has been done on the effect of herbicides and insecticides on VAM fungi. Paraquat and Simazine are toxic to these fungi, whereas Trifluralin, Bromacil and Diuron are nontoxic. The insecticides Metsystox and Aldrin differ in their activity on VAM fungi, the former being less toxic than the latter.

Many pesticides contain heavy metals, and the presence of such metals in soils may be responsible for poor germination of these fungi (Hepper and Smith, 1976). In highly acid soils, especially those of the tropics, Manganese and Aluminium may be more soluble and reach concentrations that limit growth of these fungi. Selecting pesticides with no adverse effect on VAM fungi but reducing contaminants in pot cultures will be useful in the maintenance and mass production of these fungi (Menge, 1984).

***Salinity*:** Sodium and chloride ions inhibit spore germination of VAM fungi (Gildon and Tinker, 1983). Bowen (1980) found typical VAM colonization and spores in a soil with more than 5000 ppm chloride. There are several reports of VAM fungi in maritime salt marshes (Mason, 1928). It is not known whether the endophytes involved show a special adaptation to the saline conditions. Bowen (1980) hypothesized that VAM fungi could counteract some forms of soil toxicity by absorbing elements harmful to plants or assisting plant tolerance of high alkalinity or high salinity in tropical soils.

***Organic Matter*:** Organic matter influences soil structure, pH, nutrient profile and water-holding capacity, all of which may directly and/ or indirectly influence VAM development and efficiency. According to Sheikh *et al.*

(1975), endogonaceous spore population seems to be closely correlated with the level of organic matter content in Pakistani soils. Maximum spore numbers were recovered from soils containing 1-2% organic matter and spores were sparse in soils with below 0.5% organic matter. No such correlation has been observed in temperate soils with higher (2-13%) organic matter contents, although organic manures often enhance mycorrhizal development in tropical soils (Johnson and Michelini, 1974).

An aspect of the study of organic matter that deserves attention is the impact of mycorrhizal root residues themselves on the ecology of VAM fungi in soil. Numerous mycorrhizal plants are annuals and mycorrhizal root systems are thus continuously being incorporated into soils and degraded by soil microorganisms. Almost nothing is known regarding the fate of the endophyte mycelia outside and inside the root tissues.

Redhead (1977) suggested that seasonal dieback of Sudan and Sahel savanna grasses could stimulate endogonaceous spore production, thus increasing spore populations, as observed when arable crops such as maize, barley and wheat are harvested. Mycorrhizal root debris in soil can also be an important reservoir of inoculum. Daft *et al.* (1980) claimed that most infections of *Endymion non-scriptus* in nature arose directly from the decaying old root systems through which the new roots grew and Warner and Mosse (1980) indicated some saprophytic ability of VAM fungi in soil that would enable them to establish a base (possibly in particles of organic material) from which they could infect a host plant. Many authors have emphasized that spores are not important for maintaining infection when colonized roots are present especially in the case of natural plant communities when VAM fungi may be non-sporing or poorly sporing types (Sparling and Tinker, 1978). Rives *et al.* (1980) also suggested that in areas with low annual rainfall, contact between colonized root debris and roots of uninfected plants may constitute the most efficient mode of mycorrhizal spread.

2.5 Biological Interactions with VAM Fungi

In 1904, Hiltner coined the term *rhizosphere* to denote the region of the soil subjected to the influence of plant roots and characterized by intense microbial activity. Many workers have subsequently shown that the microflora of the rhizosphere differs both quantitatively and qualitatively from that in the soil beyond the influence of the root (Parkinson, 1967; Bowen, 1976 and Bagyaraj, *et al.* 972). The rhizosphere effect was greatest with bacteria followed by actinomycetes and fungi. The increased microbial activity in the rhizosphere has been attributed to the extra nutrients available in the region. The extra nutrient supply comes from the root exudates, sloughed-off parts of the root cap, mucigel, root hair residues and abraded epidermal cells (Rovira, 1979 and Tinker, 1980). The microflora of the rhizosphere could influence plant growth in many ways as all plant nutrients pass through this region (Rovira, 1967 and Nye, 1977).

Of the various microorganisms colonizing the rhizosphere, VAM fungi occupy a unique ecological position as they are partly inside and partly outside the host. The internal phase of a mycorrhizal fungus does not encounter competition and antagonism from other soil microorganisms and has an ensured source of nutrients from the host. This advantage enables them to achieve a large and more functional biomass in more intimate contact with the root and thus increases their chances of exerting a greater effect on plants than other microbial species restricted only to the rhizosphere.

Certain generalizations and conclusions about the interactions of VAM fungi with other soil organisms can be drawn. VAM markedly improve nodulation and nitrogen fixation by legume bacteria mainly by providing high phosphorus required for the fixation process. Mycorrhizal plants also allow introduced populations of beneficial soil organisms like *Azotobacter* and phosphate solubilising bacteria to maintain higher numbers than around nonmycorrhizal-plants and to exert synergistic effects on plant growth. In

general, VAM fungi decrease the severity of root diseases. Summary of some important interactions between VAM fungi and beneficial soil organisms are presented in Table 2.2.

Table 2.2 Summary of important interactions between VAM fungi and beneficial soil micro-organisms.

Groups	Species	Interactions
N-fixation bacteria	*Rhizobium* sp.	Increased VAM infection level, nodulation, N-fixation and plant growth
Free living N-fixation bacteria	*Azotobacter* sp. *Beijerinkia* sp. *Clostridium* sp. *Azospirillum* sp.	Increased VAM infection level, VAM spore production and bacterial population
Phosphate solubilizing bacteria	*Pseudomonas* sp. *Agrobacterium* sp.	Good bacterial population in rhizosphere of mycorrhizal & non-mycorrhizal plants
Phosphate solubilizing fungi	*Aspergillus niger* *Penicillum funiculosum*	Availability of P increased by P- solubilizing fungi & uptake increased by VAM

2.6 Production of VAM inoculum

Identification of efficient indigenous strains of VAM fungi along with suitable host and substrate is a pre-requisite for mass production of VAM inocula. Plant growth period of 2-3 months gives a large crop of mycorrhizal spores to produce sizable amount of inoculum. VAM inoculum can also be produced under sterile environment by using hydroponic cultures and transferred organ culture techniques. Although, these techniques have not reached commercialization due to certain limitations.

2.6.1 Inoculation methods:

For successful mycorrhizal infection, the inoculum is placed in the root zone of actively growing plants, which are not heavily fertilized. The quantity of infection by the introduced endophytes depends on placement, inoculum potential, inoculum density, type of inoculum and environmental factors. Various methods proposed for placement of the inoculum are as follows:

***Layering or pads*:**

Inoculum is placed in layers or pads beneath seeds such that the roots penetrating the inoculum will get infected. Presently, it is one of the most effective methods of inoculating plants with VAM fungi. Layering on small and large scale can be done by using manual planters and tractor drawn seeders, respectively.

***Banding or side dressing*:**

In this method, VAM inoculum is placed to sides of seedling or seeds in the zone of root proliferation. Banding mycorrhizal inoculum 5 cm deep and 5 cm away from 2 month old citrus seedling was found to be as effective as placing the inoculum directly on the roots at transplanting and more effective than seed pelleting.

***Mixing soil with inoculum*:**

Mixing mycorrhizal inoculum with soil is the most natural method for inoculating plants. However, it requires large amount of inoculum to obtain rapid infection. Generally, this method is used for inoculating plants in nursery.

***Seed pelleting*:**

In this method, inoculum is extracted from a pot culture by wet sieving and decantation, root retained on 1 mm sieve are fragmented and added to the inoculum. Five ml aqueous solutions (1% w/v) of methyl cellulose and calcium carbonate are mixed with 35 ml of mycorrhizal sievings. This material is poured over seeds (amount depending upon the crop species), mixed thoroughly and seeds are dried.

***Pre-inoculation of transplanted seedlings*:**

In this method, inoculum is placed in the seedbeds and seedlings are transplanted when these get adequately infected. The method is useful with crops like onion and tomato.

2.7 Summary of Literature of Available on VAM Fungi of Important Agroforestry Tree Species of Bundelkhand Region

In literature, a few references on mycorrhizal work on Ber, under nursery conditions are available, whereas no publications could be traced on Chironji, Lasoda and Aonla. Studies conducted on *Zizyphus mauritiana* raised in pots and inoculated with *Glomus fasciculatum*, *G. mosseae* or *Scutellospora calospora* showed that *G. fasciculatum* was significantly more efficient than the other two VAM fungi in increasing seedling biomass and uptake of nitrogen, phosphorus, potassium, calcium and magnesium after 98 days of inoculation (Mathur and Vyas, 1996). Guissou *et al.* (1998) studied the response of *Zizyphus mauritiana* to inoculation with five species of VAM fungi, *Acaulospora spinosa, Glomus mosseae, Glomus intraradices*, *Glomus aggregatum* and *Glomus manihotis.* This was measured as root colonization, mycorrhizal dependence (MD) and phosphorous concentration in shoot of plants. Root colonization by *A. spinosa, G. aggregatum* and *G. manihotis* was high and tree growth increased significantly. *G. intraradices* also colonized well, but provided little growth benefits. *G. mosseae* colonized poorly and did not stimulate plant growth. The combination of *Z. mauritiana* and *A. spinosa* was the most responsive with respect to total biomass production and phosphorus (P) absorption.

***Albizia lebbeck* (Desi Siris):**

Occurrence of various VAM species has been reported in rhizosphere of *A. lebbeck* from normal and disturbed sites from various states of India viz. Andhra Pradesh (Srinivas *et al.,* 1999), Uttaranchal (Thapar *et al.,*1992), coal mine overburden dumps of Madhya Pradesh (Chandra and Jamaluddin, 1999 and Dugaya *et al.,*1996) and coal, lignite and calcite mine spoil of South India (Ganesan *et al.,*1991). Habte and Musoko (1994) classified *A. lebbeck* as highly mycorrhizal dependent species.

Rahangdale *et al.* (1998) studied the efficiency of 12 VAM inoculants for six forest tree species, including *Albizia lebbeck.* A significant increase in plant height, dry biomass and tissue P was observed in VAM inoculated plants. Synergistic interactions have been reported by several workers (Suvarna *et al.,* 2002; Raizada *et al.,* 1998 and Pokhriyal *et al.,* 1992) between AM fungi and *Rhizobium*, in *A. lebbek.*

Kumar *et al.* (1999) reported that Carbendazim inhibited VAM root colonization in *Sesbania grandiflora* and *A. lebbeck,* where as Quinalphos and 2,4-D enhanced percentage of infection and number of mycorrhizal propagules in both species. Udaiyan *et al.,* (1996) reported that seedlings in Formaldehyde fumigated beds had stunted growth and were chlorotic, had poor VAM root colonization and spore density. Total biomass and field survival rates of the seedlings were very low. In contrast, seedlings from Fytolan drenched beds showed normal growth, enhanced biomass and a higher field survival rate, intense VAM root colonization and higher spore density.

***Azadirachta indica* (Neem):**

Different VAM species have been reported in rhizosphere soil of neem (*Azadirachta indica*) from different states of India. Bala *et al.* (1989) reported more than 50% root colonization. *Glomus* and *Gigaspora* were common VAM genera and roots were associated with VAM infection up to 250 cm depth. Mohan *et al.* (1995) studied root and rhizosphere soil samples of neem from various Forest Department nurseries and plantations in Rajasthan. They reported that mean number of VAM fungal propagules and percentage root infection of plants were greater in plantation samples than in nursery samples. *Glomus* species was dominant in nurseries (5 species) and plantations (9 species). *Sclerocystis* species was also common in plantations. Among the *Glomus* species, *G. fasciculatum* was predominant in nurseries and plantations. Pande *et al.* (1999) reported three VAM genera from rhizosphere soil of neem viz., *Glomus* (80%), *Gigaspora* (16%) and *Acaulospora* (4%). Mohan (2000) recorded the presence of *Glomus fasciculatum, G. aggregatum*

and *G. microcarpum* from rhizosphere of *Acacia nilotica, A. tortilis, Azadirachta indica, Prosopis cineraria, P. juliflora* and *Tecomolla undulata* in nurseries and plantations in different location of Rajasthan. Mehrotra, *et al.* (2000) studied the composition of VAM fungi in the rhizosphere of poly-pot raised seedlings of *Acacia nilotica, A catechu, A. mangium, A. auriculiformis, A. tortilis, Dalbergia sissoo, Azadirachta indica, Michelia champaca, Pterigota alata, Tecomolla undulata, Paulownia fortunoi* and *P. tomentosa.* The seedlings were procured from forest nurseries in Uttar Pradesh, Haryana, West Bengal and Rajasthan. In all tree species except for *Michelia champaca* and *Pterigota alata, Glomus* predominated, followed by *Acaulospora.* Gigasporaceous fungi (*Gigaspora* and *Scutellospora)* were present in some *Acacia* species from most of the locations and in *D. sissoo* from some of the locations. *Gigaspora* was present in insignificant numbers in *Azadirachta indica.*

Beneficial effect of inoculations with different species of VAM fungi on neem seedlings have been reported by some workers. Phavaphur *et al.* (1996) studied the growth and nutrient uptake of neem seedlings in response to inoculation with the *Glomus intraradices* at two levels of phosphorus (0.65 and 1.30 mMP). Growth of VAM plants was similar at both P levels, while the growth of non-colonized (non VAM) plants increased with increasing P supply. At the low P level, VAM plant had greater leaf area, shoot, root and leaf dry weight and a greater root: shoot ratio than non–VAM plants. The study showed that VAM inoculations were beneficial for growth enhancement and nutrient uptake under low phosphorus conditions. Sumana and Bagyaraj (1999) showed that among nine VAM fungi tested, neem seedlings responded best to inoculation with *Glomus mosseae* followed by *G. fasciculatum* with regards to plant height, stem girth, bio-mass, phosphorus content, zinc concentration, bio-volume index, mycorrhizal root colonization and spore number in the root zone soil.

In literature, some reports on effect of management practices on colonization of neem plants are available. Srinivasan *et al.* (1996) reported that effluent irrigation significantly increased the root infection and spore numbers of VAM species in *Azadirachta indica*. Pande *et al.* (2002) screened different strain of VAM fungi for their tolerance to varying level of P, salinity and soil moisture while infecting neem. *Glomus mosseae* was found to be the more saline-resistant species as compared to *Glomus fasciculatum, Gigaspora margarita* and mixed inocula. The maximum infection was observed when soil was maintained at 30-60% of available water in plants inoculated by different VAM species. *Glomus fasciculatum* sporulated the most, stimulated the highest biomass production and was recommended for propagation of neem seedlings in the nursery.

Kalavathi and her co-workers (2000) have reported the synergistic effect of inoculations with VAM fungus *(Glomus fasciculatum)* and phosphorus solubilizing bacteria *(Pseudomonas striata* or *Bacillus polymyxa)* on growth and nutrient uptake of neem seedlings.

***Dalbergia sissoo* (Shisham):**

Occurrence of various VAM species have been reported in rhizosphere soil of *Dalbergia* species from different part of India, under divergent conditions. Jamaluddin *et al.* (2001) reported that *Glomus* was dominant species with different trees including *Dalbergia sissoo*, in a sludge garden of Ballarpur Paper Mill, Maharastra. Reported species included *Glomus deserticola, G. leptotichum, G. intraradices, G. mosseae, G. aggregatum* and *G. invermaium.* Mehrotra *et al.* (2000) conducted study to determine the composition of VAM fungi in rhizosphere of poly-pot raised seedlings of some forest trees. *Glomus* predominated, followed by *Acaulospora* and Gigasporaceous fungi. Gurumurthy and Sreenivasa (2000) reported two predominant VAM spore types in rhizosphere soil of tamarind, shisham and casuarinas from different location (Dharwad, Prabhunagar and Sirsi) in Northern Karnataka. Thapar *et al.* (1992) reported presence of VAM fungi

from root samples of one year old *Dalbergia sissoo* seedlings, collected from nursery stocks at New Forest, Dehradun, Uttaranchal. Thapar *et al.* (1991) reported presence of 13 *Glomus* species, 1 *Scutellospora* and 2 *Sclerocystis* from three districts of Haryana (Kurukshetra, Hissar and Rohtak) from rhizosphere of *Prosopis juliflora*, *Acacia nilotica*, *Dalbergia sissoo* and *Eucalyptus tereticornis* growing in sodic soil.

Many studies on mycorrihzal development and tree growth at disturbed sites like, coal mine overburden dumps (Chandra *et al.,* 1999), copper, aluminum and coal mines (Bisen *et al.*, 1996), sodic and alkaline soils (Thapar *et al.,* 1990), degraded bhata land (Verma *et al.,* 1999), sludge dumps of paper mills (Jamuluddin *et al.,* 2001) etc. have been conducted in different parts of our country. In such experiments, data on population status of VAM fungi in rehabilitated mined sites is compared with the populations under natural vegetation and barren mine spoils. Poor spore counts have been reported on barren mine spoils, whereas reasonable number have been reported with most of rehabilitated sites. In some of these studies, percentage infections of VAM fungi have been correlated with above ground biomass of the trees and it has been suggested that application of specific strains of VAM will increase the tree growth (Dugaya *et al.,* 1996).

***Effect of cropping system*:** Rajashekhara *et al.* (1989) studied the effect of cropping system on VAM development in red-gram and sunflower. They have reported that colonization and sporulation of VAM fungi increased with decreasing distance from the trees (*Dalbergia sissoo, Dendrocalamus strictus, Tectona grandis, Leucaena leucocephala* and *Casuarina equisetifolia*). *L. leucocephala* supported the highest mycorrhizal development in both crops.

***Effect of seed source on VAM colonization*:** Devagiri *et al.* (2001) studied seed source dependent variation in mycorrhizal colonization in *Dalbergia sissoo*. Twenty nine seed sources from India and Nepal were screened to identify good mycorrhizas forming seed sources. Results indicated good

amount of variation among different seed sources with respect to VAM colonization index (24 to 54%).

Interactions with other microbes: Paroha *et al.* (2000) reported synergistic interactions between VAM and *Azotobacter* inoculation on growth and biomass production in four forestry species, including *Dalbergia sissoo.* Kaushik *et al.* (2003) studied interactions between VAM fungi, phosphorus fertilizer and water stress application on nodulation in *Acacia nilotica* and *Dalbergia sissoo*. Application of *Glomus mosseae*, P fertilizer and water significantly increased nodule formation in both tree species. Water stress conditions significantly reduced nodule number and size in *A. nilotica* but did not have significant difference in *D. sissoo*. Kaushik *et al.* (2000) studied the impact of *Glomus mosseae* inoculation on root pathogens in *Acacia nilotica* and *Dalbergia sissoo*. Results indicated that previously VAM inoculated plants significantly increased survival percentage of their hosts against *Rhizoctonia solani* and *Fusarium oxysporum.*

***Effect of fungicides on VAM*:** Two important reports are available in literature on effect of fungicides on colonization and development of VAM in *Dalbergia* species. All three fungicides tested by Jamaluddin *et al.* (1998) namely, Dithane M-45 (Mancozeb), Bavistin (Carbendazim) and Captafol enhanced infection by VAM and spore formation in the rhizosphere at 0.1% concentration. At 0.2% the fungicides suppressed VAM colonization. Seedlings growth also increased with 0.1% fungicidal treatment. In another study, Udaiyan *et al.* (1996) studied the effect of Formaldehyde fumigation and Fytolan drench on VAM fungi and nodulation in 12 leguminous forest seedlings, including *Dalbergia latifolia.* Seedlings in the Formaldehyde fumigated beds had stunted growth and were chlorotic, had poor VAM root colonization (18-25.3%), spore density (3.1-10.6/ g soil), lower nodule numbers (3-8 per plant) and nodular biomass (100-870 mg/ plant). Total biomass and field survival rate of the seedlings were very low. In contrast, seedlings from Fytolan drench beds showed normal growth, enhanced

biomass, a higher field survival rate, intense VAM root colonization and higher spore density, higher nodular number and nodular biomass than control seedlings.

***Selection of efficient VAM fungi*:** Many reports on selection of efficient VAM fungi for seedlings of *Dalbergia sissoo* and *D. latifolia* are available. The results showed that inoculated plants had greater plant height, stem girth, dry weight and P content than non-inoculated plants. They also had greater mycorrhizal root colonization and higher spore numbers in rhizosphere soil. For *Dalbergia sissoo*, Sumana *et al.* (1993) reported best results with *Glomus fasciculatum* followed by *Gigaspora margarita*. Gurumurthy *et al.* (1999) got best results with *G. fasciculatum* under unsterile and sandy clay soil. Sumana and Bagyaraj (1998) obtained best result with *Glomus leptotichum* and *G. fasciculatum* in case of *Dalbergia latifolia.*

***Leucaena leucocephala* (Subabool):** In literature, several references are available in which increase in juvenile growth of *Leucaena* seedling have been reported by inoculation with various VAM fungi viz., *Glomus fasciculatum* (Mukerji *et al.,* 1996; Puthur *et al.,*1998 and Koffa *et al.*,1995), *G. macrocarpum* (Puthur *et al.,*1998), *G. etunicatum* (Koffa *et al.*,1995 and Dixon *et al.,* 1994), *G. deserticola* (Dixon *et al.,* 1994 and Atayese *et al.,*1993), *G. intraradices* (Dixon *et al.,* 1994) and *Gigaspora margarita* (Koffa *et al.*,1995 and Dixon *et al.,* 1994) under divergent conditions. Dixon *et al.* (1994) have reported that VAM inoculated seedlings of *Leucaena* maintained slightly greater leaf water potential, leaf stomatal conductance and photosynthesis relative to the non- mycorrhizal plants at the peak of the drought treatment and after re-watering. The data suggest that VAM fungi help *Leucaena leucocephala* to avoid drought stress.

Kumar *et al.* (2000) investigated mycorrhizal dependency (MD) of 29 agro-forestry tree species representing 14 families. Species were divided into three groups: Those with high mycorrhizal dependency (*Azadirachta indica, Leucaena leucocephala, Gliricidia maculata, Sesbania grandiflora, Cassia*

siamea and *Acacia melanoxylon*), those with moderate MD (the majority), and those with no MD (*Diospyros melanoxylon, Mangifera indica, Murraya koenigii, Polyalthia longifolia, Psidium guajava, Saraca indica* and *Zizyphus mauritiana*). No correlation was observed between percentage mycorrhizal infection and MD. Manjunath and Habte (1991) suggested that species that are marginally dependent on VAM fungi (*Sesbania pachycarpa*) tend to have lower P utilization efficiency, higher P absorption rate and higher growth rates compared with moderately (*Leucaena retusa* and *S. grandiflora*) or highly (*Leucaena leucocephala)* VAM dependent species when they are not colonized by mycorrhizal fungi. It was also suggested that species differing in growth rates could differ in their mycorrhizal dependency even when they have similar root morphological characteristics. Habte and Manjunath (1991) showed that species differing in their mycorrhizal dependency differed with respect to the soil solution P concentration required for the expression of maximum VAM effectiveness, the degree to which increasing concentration of P depressed VAM infection and the pattern of immobile nutrient accumulation. Manjunath (1990) showed that highly dependent plant species have lower growth rate, low P uptake rate and higher P utilization efficiency than marginally dependent species under mycorrhizal conditions. The results illustrated that soil solution P levels could serve as a basis for categorizing plant species into distinct MD groups. Among plant characteristics studied, root morphological characters were observed to be the most important determinants of MD.

Bansal *et al.* (1998) showed the mycorrhizal fine root litter of *L. leucocephala* worked as an effective bio-fertilizer, contributing to a several fold increase in the growth of *Zea mays.* Root litter with VAM inoculation had no additional effect. Harinikumar and Bagyaraj (1995) studied the active spread of *Glomus fasciculatum* hyphae from the roots of inoculated plants through soil was studied using rectangular battery boxes partitioned into 3 compartments, planted with mycorrhizal *L. leucocephala*, non-mycorrhizal *L.*

leucocephala and an unplanted one in the middle, filled with soil. Care was taken to prevent root growth from one compartment to the other. The results showed that mycorrhizal hyphae grew to a distance of 300 mm in 180 days. The un-inoculated plants became mycorrhizal after 180 days, confirming the active spread. Bansal and Mukerji (1994) showed that the presence of specific mycoflora in the rhizosphere of mycorrhizal roots was mediated through root exudates rather then being an outcome of improved P nutrition. Soedarjo and Habte (1993) concluded that organic matter, in appropriate amounts, could protect sensitive plants and VAM symbiosis against Al toxicity in acid soils. Maximum mycorrhizal inoculation effects are not likely to be attained unless the soils are also amended with Ca. Helal *et al.* (1998) reported increased Zn and Cu uptake by VAM inoculation in *Leucaena leucocephala.* Habte and Aziz (1991) concluded that extent of mycorrhizal colonization of *Leucaena leucocephala* increased when lost nutrient are replaced in highly eroded soils. P was the most important nutrient limiting mycorrhizal effectiveness, followed by N and lime. Soil amended with Mo at 4.4 kg/ ha increased mycorrhizal colonization of *Leucaena leucocephala* in eroded soils. However, P content was not affected by its application (Aziz and Habte, 1988). Organic residue (dried leaves and twigs of *Leucaena*) amendments at 7.38% decreased mycorrhizal colonization of *Leucaena leucocephala* by *Glomus aggregatum* (Aziz and Habte, 1988). Possible toxic effects of Mn on mycorrhizal symbiosis are briefly discussed. Aziz and Habte (1989) studied the effect of inorganic N on development of mycorrhizal symbiosis in *Leucaena leucocephala* in eroded soils. The extent of VAM colonization and P content of *Leucaena* sub leaflet increased in eroded soils at 25 ppm N. A further increase in N level did not improve above mentioned parameters. Maluf *et al.* (1988) reported that Al- intolerant cultivars of *Leucaena leucocephala* benefited more from the mycorrhiza than Al-tolerant one. The higher relative increment of shoot nutrients occurred in the Al-intolerant cultivars when colonization by *G. leptotichum* and native VAM fungi.

***VAM v\s P*:** Bagyaraj and Machado (1996) studied VAM activity in *Leucaena* at .007, .022, 0.04, 0.088 and 0.232 mg P/ litre soil solution and found it to be maximum at .022mg P/ liter. Costa *et al.* (1992) reported the possibility to reduce the level of P fertilizer of VAM inoculation in P deficient soils. Costa *et al.* (1992) reported that VAM inoculation increased dry matter yield at 0, 20, 40, 60 and 80 kg/ ha $P_2 0_5$. Highest level of VAM colonization was observed at 40 kg/ ha $P_2 0_5$. Manjunath and Habte (1992) studied the effect of inoculation of *Leucaena leucocephala* with *Glomus aggregatum* at soil solution P levels between 0.003 and 0.6mg/ litre DM yield was increased at all P levels. Costa and Paulino (1990) studied the effects of inoculation of *Leucaena leucocephala* with VAM fungi (*Glomus etunicatum, Acaulospora muricata, Gigaspora margarita* and *Scutellospora heterogama*) with and without added P (at 22 kg/ ha). Increase in dry matter yield, P and N content, VAM infection and nodulation was reported under both conditions. Manjunath and Habte (1989) reported that VAM inoculated Subabool plants were very efficient in P absorption and accumulation, but they were not superior to non-VAM plants in P utilization. Manjunath *et al.* (1980) studied the response of *Leucaena leucocephala* to VAM colonization and rock phosphate fertilization. They reported that plants associated with VAM fungi effectively utilized P from rock phosphate.

***Microbial Interaction*:** Many workers have reported synergistic interaction of VAM with *Rhizobium* in *Leucaena* (Pahwa 1995; Cao *et al.,* 1995 and Dixon et al., 1993). Some reports on enhancement of root colonization of legumes by arbuscular mycorrhizal fungi through the inoculation of the legume seed with commercial yeast (*Sacchromyces cerevisiae)* are also available in literature (Singh *et al.,* 1991 and Singh and Kapoor, 1989).

***Pesticide*:** Reports on effect of some fungicides (Formaldehyde, Fytolan, Thiram and Chlorothalonil) and one nematicide (Fenamiphos) on VAM fungi and growth of *Leucaena leucocephala* seedlings are available in literature. Habte and Manjunath (1992) studied the effect of Thiram on VAM symbiosis

in *Leucanea leucocephala*. They reported that mycorrhizal colonization of host roots was low and did not change, as the concentration of Thiram increased from 0 to 1000 mg/ kg in un-inoculated soil. In inoculated soil, colonization was high which decreased with increasing Thiram concentration. Symbiotic effectiveness was reduced and completely eliminated with increasing Thiram concentration. If, Thiram levels did not exceed 125 mg/ kg, addition of P to soil compensated for Thiram induced loss of VAM activity. Chlorothalonil reduced mycorrhizal colonization of roots, shoot P concentration and uptake and dry matter yields at all tested concentrations (Aziz *et al.,* 1991). Results of another study showed that toxic effect of chlorothalonil declined as a function of time. A significant level of toxicity persisted 12.5 weeks after application of the chemical to soil. Habte and Manjunath (1988) concluded that Fenamiphos, a nematicide is not likely to influence the growth of *Leucaena* or its symbiotic association with VAM fungi, if the concentrations applied does not exceed levels known to suppress nematodes.

***Effect of VAM on drought tolerance*:** Osonubi *et al.* (1991) concluded that the drought response index may be a useful determinant of mycorrhizal dependency, as they are inversely related. Michelsen and Rosendahl (1990) demonstrated the potential of VAM inoculated plants of *L. leucocephala* and *A. nilotica* in reforestation programmes in degraded area of arid tropics, particularly to counter drought stress following transplantation.

***Effect of VAM on enzyme activity phosphatase*:** Jagpal *et al.* (1991) reported that phosphatase activity (used to assess uptake of phosphorus) was greater in *Glomus macrocarpum* inoculated *Leucaena leucocephala* plants.

***Effect of simulated erosion of VAM*:** Aziz and Habte (1989) studied the sensitivity of three vesicular arbuscular mycorrhizal species to simulated erosion using *Leucaena leucocephala* as an indicator host. The extent of colonization of *Leucaena* roots increased significantly due to VAM inoculation of the eroded and un-eroded soils. The highest level of VAM

colonization was observed when *Leucaena leucocephala* was grown in association with *Glomus aggregatum,* followed by *G. mosseae* and *G. etunicatum*. Increased infection associated with inoculation of the eroded soil did not result in enhanced mycorrhizal effectiveness. Inoculation of the un-eroded soil, however, led to significant improvement in root colonization as well as in symbiotic effectiveness. Suppression of mycorrhizal effectiveness in the eroded soil appears to be a result of nutrient deficiency. The results showed the importance of restoring lost nutrients before differences in VAM species could be effectively exploited for successful establishment of mycorrhizal plants in eroded soils.

Habte *et al.* (1988) concluded that development of VAM effectiveness is the phase of the VAM symbiosis that is the most adversely influenced by simulated erosion and that this effect appears to be caused primarily by insufficient P in the soil solution.

***VAM v/s soil type*:** Habte and Fox (1989) evaluated symbiotic effectiveness of *Glomus aggregatum* in five widely differing tropical soils. The soils differed in the time required for expression of initial and maximum VAM effectiveness. The ratio of the area enclosed by the effectiveness curve of *G. aggregatum* to that enclosed by the effectiveness curve of a test soil was a good indicator of the response of *L. leucocephala* to soil inoculation with *G. aggregatum.*

In *Jatropha* and *Pongamia*, a very few references are available. Adholeya and Reena (2006) have reported that mycorrhizal inoculations speed up flowering and fruiting in *Jatropha curcas* and 30% increase in bio-mass was reported. Rahangdale *et al.* (1998) have reported that VAM inoculation significantly increases plant height, dry biomass and tissue phosphate in *Pongamia pinnata.*

Materials And Methods

MATERIALS AND METHODS

3.1 Description of Sites/ Fields

The study was conducted at National Research Centre For Agroforestry, Jhansi (25°27' N latitude, 78°35' E longitude and at about 271 m above msl). On agro-ecological zone map of India, Jhansi lies in the hot semi-arid zone. Three distinct seasons are recognized in a year. Summer (March-Mid June) is hot and dry, rainy season (Mid June- September) is warm wet and winter (October- February) is cool dry. The area receives annual rainfall between 700-1150 mm mostly during monsoon period (Mid June- September). The mean maximum temperature varies from 23°C (January) to 42°C (May). Correspondingly mean minimum temperature varies from 5°C (January) to 26°C (May). Meteorological data of NRCAF, Jhansi during experimental period is presented in Appendix I.

The main soil types at the experimental fields were red and black. Red soils occurred at elevated spots in the field. These were shallow, gravelly, light textured, pH varied from 6.08 to 6.70 and organic carbon varied from 0.38% to 0.65%. Black soils were situated in comparatively low lying areas and were fine textured, highly water retentive, pH varied from 5.70 to 6.78 and organic carbon varied from 0.41% to 0.67%.

A total of 96 plants were selected, which consisted of 48 Aonla (*Emblica officinalis* Gaertn.), 28 Ber (*Zizyphus mauritiana* Lamk.), 12 Lasoda (*Cordia myxa* Roxb.) and 8 Chironji (*Buchanania lanzan* Spr.) plants. The selected trees were from six sites viz., National Research Centre For Agroforestry, Jhansi campus (NRC), Nagar Palika Baruasagar, district Jhansi (NPB), village Katili, Jhansi (VKJ), village Nareta, Datia (VND), village Jakhlon, Lalitpur (VJL) and Nilkanthh, Pauli (NP) (Fig. 3.1). Among Aonla plants, 40 were from NRC and four each from NPB and VKJ. Aonla plants at NRC were selected from four different fields such that these covered three

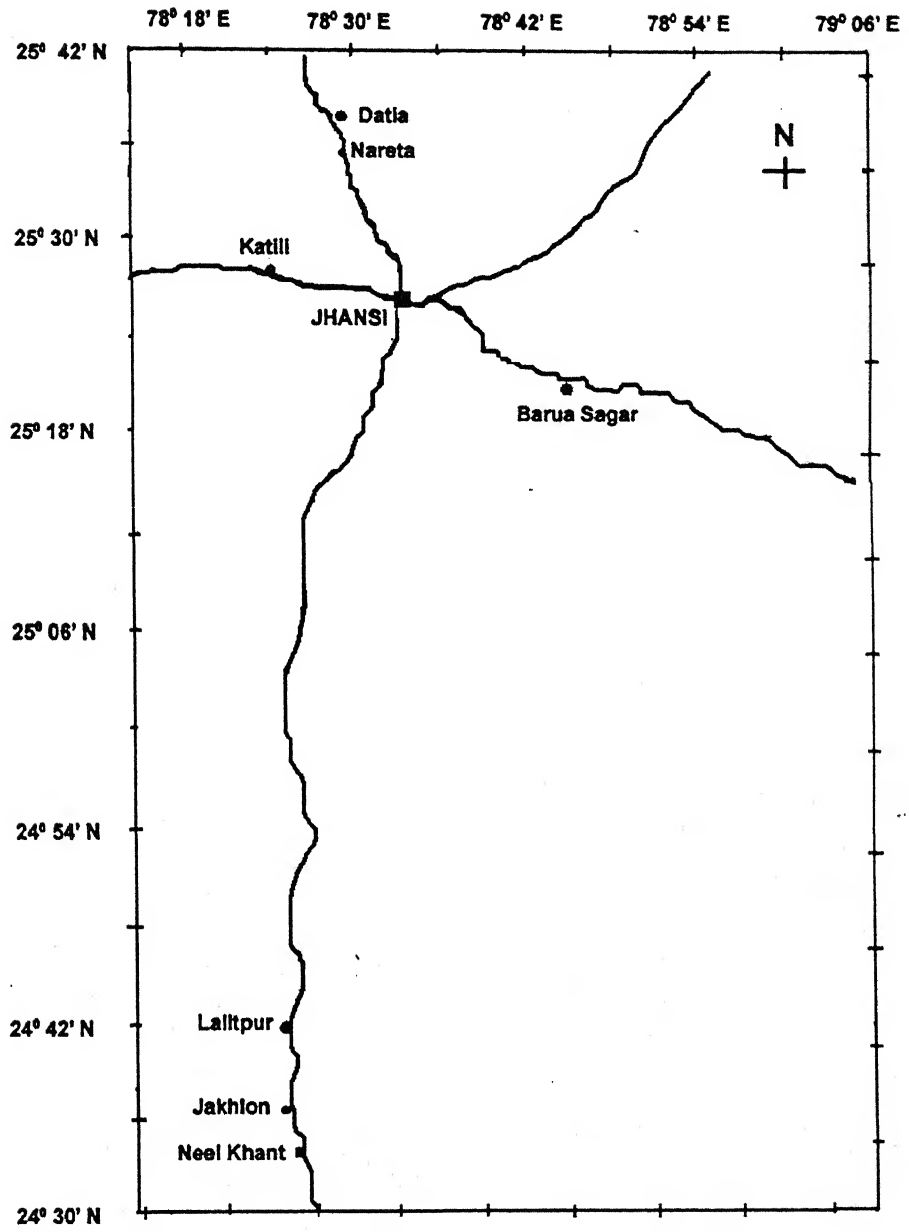


Fig. 3.1 Location of diffrent sites from where root / soil samples were collected from rhizosphere of selected minor fruits.

varieties of the fruit crop (Kanchan, Krishna and Chakaiya), three soil types (red, black and lateritic) and upland/ lowland plants. Marked plants of Aonla from NPB and VKJ were from a single field, at respective sites. All selected Ber plants were from NRC and covered its different varieties/ strains viz., Banarasi Karaka, Gola, Seo, Desi, Makor, Ghot and Jhar-beri. Eight plants of Lasoda were selected from NRC, four from block plantation and four from silvipasture system. Four plants of Lasoda were selected from a village Nareta in Datia district of MP. Among Chironji plants, four were from a village Jhakhlon in Lalitpur district and other four were from Nilkanthh, Pauli (MP). (Table 3.1).

Table 3.1 Description of sites/ fields

Fruit tree	Site	Number of plants	Remarks
Aonla	NRCAF	40	Cover 3 varieties, 3 soil types, uplad and lowland plants
	Katili	04	Desi plants and red soil
	Baruasagar	04	Desi plants, red soil and Irrigated
Ber	NRCAF	28	Cover 7 varieties/ Wild relatives
Chironji	Jhakhlon	04	Dry and un-cultivated land
	Nilkanthh	04	Spring water
Lasoda	NRCAF	08	4 silvi-pasture and 4 block plantation
	Nareta	04	Black fertile soil

3.2 Sampling

Root and rhizosphere soil samples of Aonla, Ber, Chironji and Lasoda were collected from selected sites/ fields during July 2003 - June 2005. Reasonable care was taken while taking root samples such that it contained sufficient terminal feeder roots. To obtain representative samples of entire root system, roots were taken from four or five different portions of the root system and combined. The samples were either processed immediately after sampling

or preserved in standard formalin-aceto-alcohol (FAA) solution. FAA was prepared with 50% alcohol with V/V/V ratio of 90:5:5.

3.3 Clearing and Staining Root Specimens

3.3.1 Reagents:

- 10% Potassium hydroxide solution
- Alkaline H_2O_2

  25% Ammonium solution : 3 ml

  10% H_2O_2 : 30 ml

  Distilled water : 567 ml
- 1% HCl
- Lactoglycerol

  Lactic acid : 876 ml

  Glycerine : 64 ml

  Distilled water : 60 ml
- Staining solution

  0.01% Acid fuschin : 0.01 g acid fuschin in 100 ml lactoglycerol

  0.05% Trypan blue : 0.05 g trypan blue in 100 ml lactoglycerol

3.3.2 Procedure: Clearing and staining of root specimens was done following the method of Phillip and Hayman (1970). Root samples, collected from field were washed under running tap water thoroughly, placed in glass vials containing 10% KOH solution and heated at 90°C for about 1 hour. The KOH solution clears the host cytoplasm and nuclei and readily allows stain penetration. After heating, KOH solution was poured off and the root samples were washed using at least three complete changes of tap water or until no brown colour appeared in the rinse water. Washed roots were placed in alkaline H_2O_2 at room temperature for 1 hour or until roots were bleached. Then the roots were washed with tap water thoroughly using three changes. The alkaline H_2O_2 solution was made as per need as it loses its effectiveness on storage. After H_2O_2 treatment, the samples were treated with 1.0% HCl for

30 minutes and then the solution was poured off. The roots were not rinsed with water after this step because these must remain acidified for proper staining. The root samples were kept in 0.01% staining solution (acid fuschin) after HCl treatment and kept at 90°C for 1 hour. After removing fuschin solution the root specimens were placed in de-staining solution for mycorrhizal assay. The specimens were not washed with water after staining because the stain is readily removed from the fungal structures. The de-staining solution was the standard staining solution as mentioned above, without the stain.

3.4 Mycorrhizal Assay

Mycorrhizal colonization percentage was determined by grid line intersection method of Giovannetti and Mosse (1980). Root segments, each approximately 1 cm long, were selected at random from stained samples and mounted on microscopic slides in groups of 10. Twenty root segments from each sample were used for assessing length of cortical colonization in millimeters, at 100 X. Average of the readings from a sample, were expressed as percentage of root length colonization.

3.5 Separating Spores from Soil

Spores were isolated from soil according to the method of Gerdemann and Nicolson (1963) and counted (Gaur and Adholeya, 1994). Depending upon spore numbers and soil texture, 50-100 g soil samples were weighed. This allowed spore number to be expressed relative to soil weight. Generally less than 100 g of soil was best, but larger samples were used if spore population in soil was low. Vigorous washing was avoided. Soil was mixed in a substantial volume of water and decanted through a series of sieves. Roots and coarse debris was collected on a coarse sieve, while spores were captured on one or more fine sieves. Sievings were then collected in jars. For observation under stereo-microscope, the sievings were transferred onto the

grided petri dishes (11cm). Number of spores were counted and expressed as spores per unit of the soil sample.

3.6 Preparation of Diagnostic Slides

3.6.1 Reagents:

- Polyvinyl alcohol-lactoglycerol (PVLG) mountant

  Polyvinyl alcohol : 8.30 g
  Distilled water : 50 ml
  Lactic acid : 50 ml
  Glycerine : 5 ml

- Meltzer's reagent-Mixed 1:1 (v/v) with PVLG

  Chloral hydrate :100 g
  Distilled water :100 ml
  Iodine : 1.5 g
  Potassium iodide : 5 g

3.6.2 Procedure: After isolating VAM spores from soil, diagnostic slides were prepared by using the methods of Schenck and Perez (19). Clean spores were picked up with a pipette and placed in a watch glass with distlled water. A drop of mountant was placed on left and right side of a clean and dry microscope slide, allowing space on one end for a label. The spores were added with minimum amount of water to the mountant. The spores and mountant were mixed gently with a needle to disperse the spores. The mountant was allowed to set for 3-5 minutes, which became more viscous before adding a cover slip. During this time, spores were positioned in the center of the drop with proper orientation, so that the desired features were visible. A clean and dry cover slip was moved at 45° angle toward the mountant. After contact, few seconds were allowed for the mountant to spread along the cover slip surface. The cover slip was released gently, onto the mountant. This minimized formation of air bubbles. No pressure was applied to the cover slip. The relevant steps were repeated with the second drop of

mountant. Applying little pressure on the cover slip with an eraser or with your thumb broke spore wall of mycorrhizal spores, under one cover slip. Mountant with spores was dried for several hours or overnight in a flat position. After this period, broken spores were examined. It is important that the break of the walls should be adequate. Excess mountant was cleaned with a cotton swab moistened with a solvent such as ethanol. Edges of the cover slip were sealed with clear fingernail polish or other sealant and the sealant was allowed to dry. The observations were made as listed on the INVAM Worksheet (Appendix II) and additional slides were made, if the condition of the spores on the first slide was not adequate for a detailed examination.

3.7 Identification of VAM Genera

There are only six genera of fungi that contain species, which are known to produce arbuscular mycorrhizae with plants. Two of these genera, *Glomus* and *Sclerocystis*, produce only chlamydospores. Four genera from spores that are similar to zygospores (referred as azygospores in further descriptions) namely, *Gigaspora, Scutellospora, Acaulospora* and *Entrophospora*. The genera are distinguished by their spore characteristics and the relationship of the spore to the associated hyphal attachments. The existent genera were established to reflect the manner in which the spores were produced, except for the genus *Scutellospora*. Species in this genus are distinguished from species in the closely allied genus *Gigaspora* by wall characteristics, method of germ tube formation, and auxiliary cell characteristics. VAM fungal spores from rhizosphere soil of various tree species were identified following the keys of Trappe *et al.* (1982) and Schenck and Perez (1987).

1a Spores produced as chlamydospores 2

1b Spores not produced as chlamydospores 3

2a Sporocarps only with spores radiating from a central core of hyphae ..... *Sclerocystis*

2b Spores formed singly in soil or in sporocarps; if in sporocarps, spores not radiating from a central core of hyphae..... *Glomus*

3a Azygospores formed near or below a swollen hyphal terminus 4

3b Azygospores formed on a swollen hyphal terminus 5

4a Spore formed laterally on hypha, below a swollen hyphal terminus ..... *Acaulospora*

4b Spore formed within the hypha, below a swollen hyphal terminus ..... *Entrophospora*

5a Spore with 2 or more wall groups, the inner containing a coriaceous or membranous wall ..... *Scutellospora*

5b Spore of only 1 wall group, auxiliary cells echinulate or finely papillate ..... *Gigaspora*

Many observations required for the separation of genera were made with a stereo-microscope. Spores were viewed in water in reflected/ transmitted light to observe hyphal attachments. Spores were rolled or turned so that attachments were not obscured. Spores placed in PVL or PVLG (viscous mountants) were properly oriented.

3.8 Trap Culture/ Inoculum Production

Rhizosphere soil collected from selected plants of Aonla, Ber, Chironji and Lasoda was used for inoculum production. It was mixed in 1:1 ratio (v/v) with autoclaved coarse sand. The mixture was transferred to 15 cm plastic pots, which were seeded with maize and black-gram. The cultures were grown in a greenhouse for at least four months. Some sporulation occurred during first three months, but it was during the fourth month when plant shoots (and

roots) had ceased growth and carbon seemed to be repartitioned to sporulation rather than mycorrhizal development. A longer time was avoided because other fungi, which often contaminate the cultures. Fertilization was kept to a minimum, being applied only when plants showed signs of phosphorus deficiencies (purpling of leaf sheaths) or nitrogen deficiency (chlorosis of young leaves). Pots were left to dry undisturbed in a shaded room with a fairly stable temperature so that the drying period was not too rapid (1-2 weeks). For trap cultures that were propagated for 1-2 additional cycles, the bagged material was used as inoculum (undiluted) within 30 days of harvest. If sporulation was extremely low, then the pots were not harvested, but shoots removed and the pot contents reseeded.

3.9 Establishment Monospecific Cultures

3.9.1 Spore collection: Spores were extracted by wet sieving and decantation method from the pot culture material 2-3 days before inoculation onto plant seedlings. After repeated washing, the spores of each target species were collected manually and stored in a watchglass (sealed in petri dish) at 4^0C. Spores were examined daily until the day of inoculation and any with changed morphology (loss of contents, collapse and color change) or suggestion of parasitism were removed. Before inoculation, water was added to the spore preparation, the watch glass agitated and any particles, hyphal fragments or atypical spores were removed. Cone-trainers (presterilized in 10% bleach) were first filled to the top with sterile sand-soil mix, labels applied and 6-7 cm deep holes were made in centers with a sterile glass rod. An alcohol lamp and a beaker of 95% ethanol are set up for flaming the glass rod after each transplant operation.

3.9.2 Seedling preparation: Approximately 12 days before a monospecific culture was planned on being set up, approximately 40-50 sorghum seeds were evenly spaced in a 15-cm diameter pot using our standard sand-soil mix. This seeding rate provides enough seedlings for a given "run", and they were far

enough apart to separate without much damage to root systems. Sorghum was used because it has a hardier root system that buffered the seedling against transplant shock. By 12 days, pot contents were removed intact. This mass was placed in a large glass bowl filled with water so that it was completely immersed. Roots were gently teased from the growth medium and from each other and then left undisturbed for at least 30 minutes.

3.9.3 Inoculation: Three seedlings were gently collected, spores (in 200 µl water) were pipetted along the length of the intertwined roots, so they were in contact with the maximum range of root physiological states. Spores adhere naturally while excess water drips from root tips. Seedlings were immediately transplanted into the center hole of a cone-trainer. The glass rod was used to refill hole and compact soil around seedlings until they stand upright. Care was taken to distribute roots along length of the hole. Cone-trainers were topped off with sterile growth medium all cone-trainers were watered gently and placed in a room with indirect lighting for 24 hours and then moved to greenhouse. Cone-trainers are not fertilized for at least 14 days after transplantation to optimize initial mycorrhizal development.

3.10 Mass Culture

Isolated spores were surface sterilized and subjected to mass culturing, for which, sterilized sand was filled in 1.8 kg capacity plastic pots. The pots were inoculated @ 900 spores/ pots (300 spores/ seed site, 3 sites per pot). Sterilized maize seeds germinated on towel paper were placed right above the VAM inoculum. Pots were watered on alternate days with de-ionized water and ¼ strength Hoagland's (Appendix III) solution was supplied at weekly intervals. The pots were subjected to 3 cycles of plant growth, as described for trap culturing. This gave a ready to use homogenous inoculum of indigenous VAM fungi.

3.11 Most Probable Number (MPN) Method

Prior to use of the inoculum, a serial dilution technique was applied to ascertain the number of infectious propagules (Porter, 1979) as follows:

1. 350 g sterile soil + 50 gm of soil from layer (ii) of the inoculum pots
2. 85 g of soil from step (1) + 255 g of sterilized soil (dilution I)
3. 85 g of soil from step (2) + 255 g of sterilized soil (dilution II)
4. 85 g of soil from step (3) + 255 g of sterilized soil (dilution III)
5. 85 g of soil from step (4) + 255 g of sterilized soil (dilution IV)
6. 85 g of soil from step (5) + 255 g of sterilized soil (dilution V)

Aliquots (50 gm) of substrates containing various levels of the inoculum were placed in plastic pots (height 9.5 cm, diameter 9.5 cm), filled with 150 gm of sterilized soil. Maize seeds were sown and layered with sterilized soil. Five replications of each dilution were maintained. Harvesting was done after 6 weeks by carefully cutting the pots and critically recognizing the layers. Only the roots from the II^{nd} layer (fig. 3.2) were stained according to Phillips and Hayman (1970) as follows:

Fine roots were heated with 10% KOH for 45 min., washed with water, placed in 2% HCl for 5 minutes and stained with 1.0% trypan blue in glycerol for 24 hours, de-stained in 50% glycerol-water (v/v) for 12 hours. Subsequently the roots were observed for infection, designated by + or – for infected or non-infected roots respectively.

MPN was calculated using the formula:-

$\text{Log } \Omega = x \log a - k$

Where Ω = number of infectious propagules,

x = mean number of cups with infection i.e. x = total number of infected cups/ number of replications/ dilution

a = dilution factor

In order to define the value of 'k', the values of x & y are required where

y = s – x and

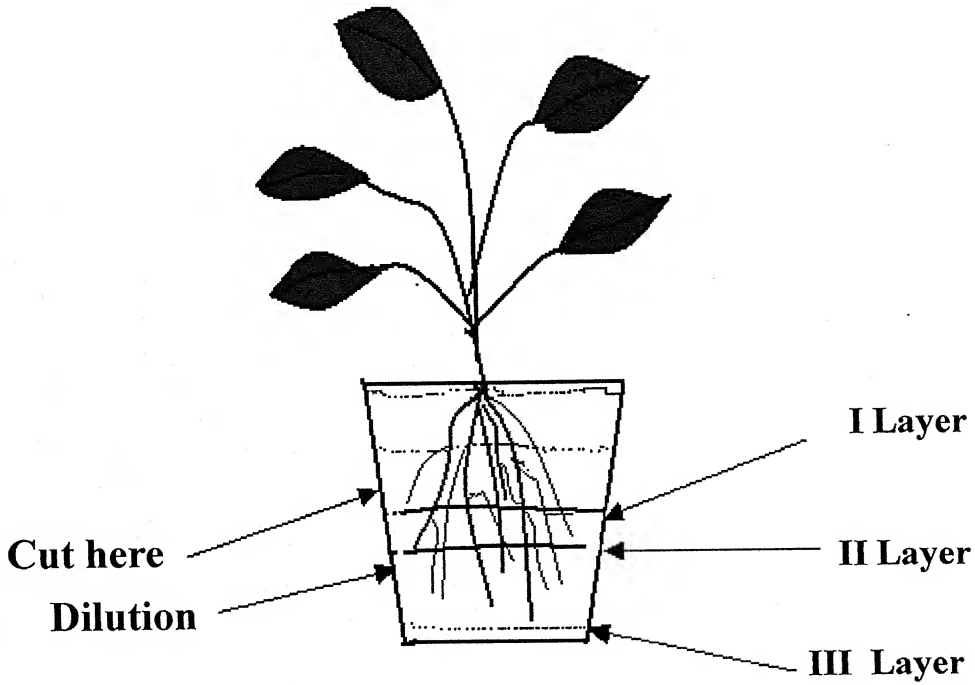


Figure 3.2 A schematic diagram showing the manner of using root fragments for MPN

S = number of dilution level

'k' value is then determined from Table VIII of Fisher and Yates (1963) for the given values of 'x' & 'y' (Appendix IV).

3.12 Polyhouse Experiments

3.12.1 Screening for Efficient VAM Species: The effect of inoculation of seven VAM species, six belonging to *Glomus* and one *Acaulospora*, on the growth and development of Aonla, Ber, Chironji and Lasoda was studied. The inoculum was used from the purified cultures.

3.12.2 Substrate sterilization: Red soil was used as potting mixture, soil was passed through 2 mm sieve, moistened and filled in cotton begs which were autoclaved for 8 hours at 121^0C and 15 psi. On the following day, the begs were opened and the soil spread out for the whole day only to be rebegged and autoclaved subsequently.

3.12.3 Seed sterilization: Seeds of Aonla, Ber, Chironji and Lasoda were scaricified and surface sterilized with 0.1% mercuric chloride for 2 minutes, followed by 3 rinses in sterile distilled water.

3.12.4 Substrate and inoculum dose: Steam sterilized soil substrate was air dried and potted in 7-8 kg capacity plastic pots. At the time of sowing, 50 gm of mycorrhizal inoculum comprising of 25 VAM infectious propagules gm^{-1} was applied in the hole as per treatments. Each treatment was replicated three times. The pots were kept under controlled conditions and watered as and when required to field capacity. After germination one healthy plant were maintained in each pot. The observations were recorded after one month interval on plant height and collar diameter. After five months of sowing, the plants were harvested carefully and analyzed for the following parameters:

1. Biomass production in terms of root/ shoot fresh/ dry weight: Plants were washed in tap water followed by 0.1% HCL and repeated washing with de-ionized water. Plants were gently blotted on to a blotting paper and roots served from shoots and fresh weights were

recorded. Samples were dried in the oven at 68^{0}C for 48 hours. Their dry weights were subsequently recorded.

2. Colonization index
3. Shoot length
4. Collar diameter
5. P content in the shoot and root tissues

3.13 Build up of VAM fungi in Trees/ Intercrops

Build up of above mentioned seven VAM species in Aonla, Ber, Chironji, Lasoda and important kharif (black gram, green gram and maize), zaid (black gram, green gram and maize) and rabi (gram, pea, maize and wheat) crops was studied in sand cultures. Tree/ crops were inoculated with VAM species and inoculated pots were kept under controlled conditions. Each treatment was replicated three times. The plants were irrigated with filtered water and half strength Hoagland solution was applied twice a week. Root and soil samples were taken at monthly intervals from inoculated pots and observations were recorded on following parameters:

1. Presence of arbuscules
2. Presence of vesicles
3. Presence of extrametrical hyphae
4. Presence of spores in extrametrical hyphae
5. Presence of spores in root
6. Colonization index
7. Spore count per 100 g soil
8. Presence of sporocarp

3.14 Determination of Soil Moisture

Soil samples were taken at 0-15 cm soil depth at 0.5 m distance from tree base at 30 days intervals from April to June, 2005. The soil moisture was recorded by gravimetric method (Lal Singh, 1987) using following formula:

$$\text{Moisture \%} = \frac{\text{Fresh weight of soil} - \text{Dry weight of soil}}{\text{Dry weight of soil}} * 100$$

Took exactly 50 g soil in weighted moisture boxes and dried the samples in an oven at 105° C for 12 hours. The weight of dried soil was taken after cooling.

3.15 Soil Reaction

The pH was measured with glass electrode pH meter using 1:2.5 soil-water ratio as originally suggested by Richards, 1954.

3.16 Electrical Conductivity

The 1:2.5 soil to water extracts was subjected to EC measurements and expressed as $1x10^5$ µs cm^{-1} at 25^0C as a measure of soluble salt content (Richards, 1954).

3.17 Determination of Organic Matter

The soil samples were ground and pass through a 0.2 mm (80 mesh sieve) and Walkley and Black's rapid titration procedure was used (Walkley and Black, 1934).

3.17.1 Reagents:

1. Concentrated H_2SO_4
2. Concentrated phosphoric acid (85%)
3. 1 N Potassium dichromate solution: dissolved 49.04 g of $K_2Cr_2O_7$ in water and made volume to one liter
4. N/ 2 Ferrous ammonium sulphate solution: dissolved 196.0 g of salt in water, added about 90 ml dilute H_2SO_4 and made volume to one liter

6. Diphenylamine indicator: dissolved 0.5 g of the indicator in 100 ml concentrated H_2SO_4 and stored in a coloured bottle.

3.17.2 Procedure: Transferred 0.5 g of soil in a 500 ml conical flask and 10 ml of $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4 were added to it. Shook the mixture for 5 minutes and kept it standing for 30 minutes. If the colour of the contents changed to green or yellowish green, added 10 ml $K_2Cr_2O_7$ and left for another 30 minutes. Diluted the mixture with 200 ml water and 10 ml of phosphoric acid (H_3PO_4) and 1 ml (15-20 drops) of diphenylamine indicator were added. A deep violet colour developed. Titrated with ferrous ammonium sulphate till the colour changed first to purple and finally to green. A blank experiment was also carried out.

3.17.3 Observations:

Weight of soil taken	=	W g
Volume of N/ 2 ferrous ammonium sulphate used to reduce (neutralize) 10 ml of 1N $K_2Cr_2O_7$ (blank reading)	=	X ml
Volume of N/ 2 ferrous ammonium sulphate used to reduce (neutralize) excess of 1N $K_2Cr_2O_7$ (experimental reading)	=	Y ml

3.17.4 Calculations:

Volume of N/ 2 ferrous ammonium sulphate equal to 1N $K_2Cr_2O_7$ required to oxidize organic carbon present in the soil	=	(X-Y) ml
Volume of 1N ferrous ammonium sulphate equal to 1N $K_2Cr_2O_7$ required to oxidize organic carbon present in the soil	=	(X-Y)/ 2 ml
1 ml 1N $K_2Cr_2O_7$	=	0.003 g of carbon
(X-Y)/ 2 ml 1N $K_2Cr_2O_7$	=	$0.003 \times \frac{(X-Y)}{2}$

Percentage of organic carbon = $\frac{0.003(X-Y) \times 100}{2.W}$

= Z

Generally 58% carbon is present in the organic matter:

Therefore, percentage of organic matter = Z x 100/58

= Z x 1.724

3.18 Plant Analysis for Phosphorus

Phosphorus in plant samples was determined by using Vanadomolybdo phosphoric acid yellow colour method (Jackson, 1973). Plant samples were dried in sun, then in oven at 80^0C for two hours and ground to pass through a 1 mm sieve. The plant samples (approximately 200 g) were stored in polythene begs till further analysis.

3.18.1 Reagents:

1. Di-acid mixture: The mixture was prepared by mixing 800 ml nitric acid (HNO_3) with 200 ml per-chloric acid ($HClO_4$) in a winchister bottle.
2. Standard phosphorus solution: 50 ppm P stock solution was prepared by dissolving 0.2195 g of A.R. potassium di-hydrogen orthophosphate (KH_2PO_4) in 1 litre distilled water.
3. Ammonium molybdate - ammonium vanadate solution in HNO_3:

   Solution A: Dissolved 22.5 g ammonium molybdate in 400 ml of distilled water

   Solution B: Dissolving 1.25 g of ammonium vanadate in 300 ml of boiling distilled water.

   Solution A and solution B were added in 1 litre volumetric flask. These were cooled to room temperature, 250 ml of concentrated HNO_3 was added and the volume was made up to the mark.

3.18.2 Procedure: Digestion of plant sample in di-acid mixture: Transfer 0.5 g of oven dried plant sample in a digestion flask. Added 10 ml of di-acid to it

and the mixture was heated on a sand bath. The digestion was continued till a white residue was obtained.. If the contents of the digestion flask dried before complete digestion, 5 ml of di-acid was added and digestion was continued until white colour was obtained. After digestion, the contents were cooled, diluted with water, filtered through Whatman No. 1 filter paper and the volume was made up to the mark in a 100 ml volumetric flask.

3.18.3 Preparation of standard curve: Transferred 0, 1, 2, 3, 4 and 5 ml of standard P solution to 50 ml volumetric flask to get 0, 1, 2, 3, 4 and 5 ppm of P respectively. Added 10 ml of vandate molybdate reagent to each flask. Made up the volume with de-ionized water, shook the contents of the volumetric flasks thoroughly and read absorbance of solutions after 30 minutes at 420 nm with spectrophotometer by using blue filter. Plotted absorbance against concentration to obtain the standard curve. The slope of the curve was determined and the concentration of the unknown solutions was calculated by using the equation.

Absorbance = Slope x Concentration

For analysis of plant samples, 5 ml of the digested aliquots were used instead of standard P solution.

3.19 Statistical Analysis

Treatment effects were determined by analysis of variance (ANOVA) using a completely randomize design. A significance level of 95% was applied. The graphs were prepared by using MS Excel or SYSTAT.

Results

EXPERIMENTAL RESULTS

The present study was carried out with the aim to identify suitable VAM species for inoculation of Aonla (*Emblica officinalis* Gaertn.), Ber (*Zizyphus mauritiana* Lamk.), Chironji (*Buchanania lanzan* Spr.) and Lasoda (*Cordia myxa* Roxb.). To achieve this, a series of experiments on field surveys, identification of common VAM fungi in rhizosphere of above mentioned tree species, culturing, purification and multiplication of VAM fungi and screening of the fungi for improved seedling growth, were conducted. The results obtained from various experiments were statistically analyzed and are presented hereunder with appropriate tables and suitable graphs.

4.1 Field surveys:

4.1.1 Colonization index, spore count and species composition in rhizosphere of Aonla varieties: The data on colonization index in rhizosphere of Aonla varieties recorded during different seasons are presented in Table 4.1. Maximum colonization index was recorded in variety Krishna (22.7%), followed by Kanchan (20.0%), which were at par. Observations in these varieties were significantly superior to Chakaiya (16.5%) and NA- 7 (16.3%) and the index values were at par in Chakaiya and NA-7. Among different sampling dates, maximum colonization-index was recorded during December, 2003 (26.9%), followed by June, 2004 (26.3%), March, 2004 (24.1%) and September, 2004 (22.6%), which were at par. The colonization-index was significantly less than above mentioned treatments during October, 2004 (16.6%), August, 2004 (16.1%), October, 2003 (14.7%) and August, 2003 (13.6%). Poorest index value was recorded in July, 2003 (11.1%).

In general, Aonla varieties did not show major differences in colonization-index. The data on spore count per 100 gm soil of VAM fungi in rhizosphere of Aonla varieties are presented in Table 4.2. The counts in

Table 4.1 Colonization index of VAM fungi in some Aonla (*Emblica officinalis* Gaertn.) varieties during different sampling periods

Date of sampling	Colonization index in Aonla varieties				
	Chakaiya	Kanchan	Krishna	NA-7	Mean
July,	8.7*	11.9	12.3	11.6	11.1
2003	(17.1#)	(20.1)	(20.5)	(19.9)	(19.4)
August,	15.7	14.2	14.9	9.8	13.6
2003	(23.3)	(22.1)	(22.7)	(18.2)	(21.6)
October,	14.9	18.4	13.8	12	14.7
2003	(22.7)	(25.4)	(21.8)	(20.2)	(22.5)
December,	26.1	34.3	24.6	22.7	26.9
2003	(30.7)	(35.8)	(29.7)	(28.4)	(31.2)
March,	21.8	17.9	31.4	25.0	24.1
2004	(27.8)	(25.0)	(34.7)	(30.0)	(29.4)
June,	21.7	28.9	31.1	23.3	26.3
2004	(27.7)	(32.5)	(33.9)	(28.8)	(30.8)
August,	13.7	15.6	17.5	17.8	16.1
2004	(21.7)	(23.2)	(24.7)	(24.9)	(23.6)
September,	14.8	23.7	38.6	16.2	22.6
2004	(22.6)	(29.1)	(38.4)	(23.7)	(28.4)
October,	13.2	18.4	23.4	12.2	16.6
2004	(21.3)	(25.4)	(28.9)	(20.4)	(24.0)
Mean	16.5	20	22.7	16.3	
	(23.9)	(26.5)	(28.4)	(23.8)	
		S. Em.±	C.D. (0.05%)		
Variety		1.0	2.9		
Sampling date		1.5	4.3		
Variety * sampling date		3.1	NS		

*Average of four replications

Figures in parenthesis indicate angular transformation values

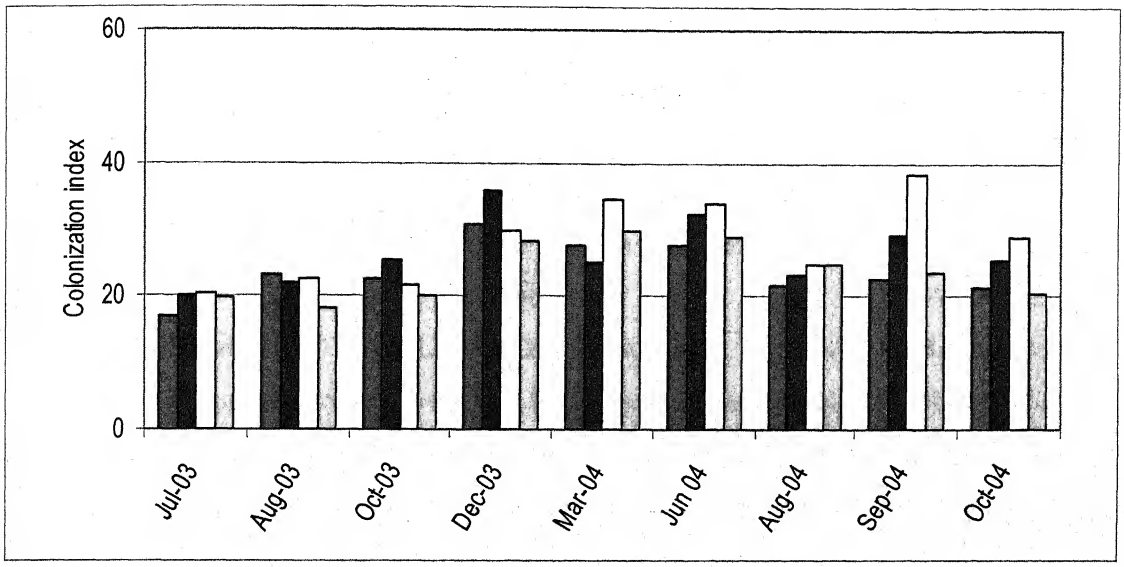
Table 4.2 Spore population of VAM fungi in rhizosphere of some Aonla (*Emblica officinalis* Gaertn.) varieties during different sampling periods

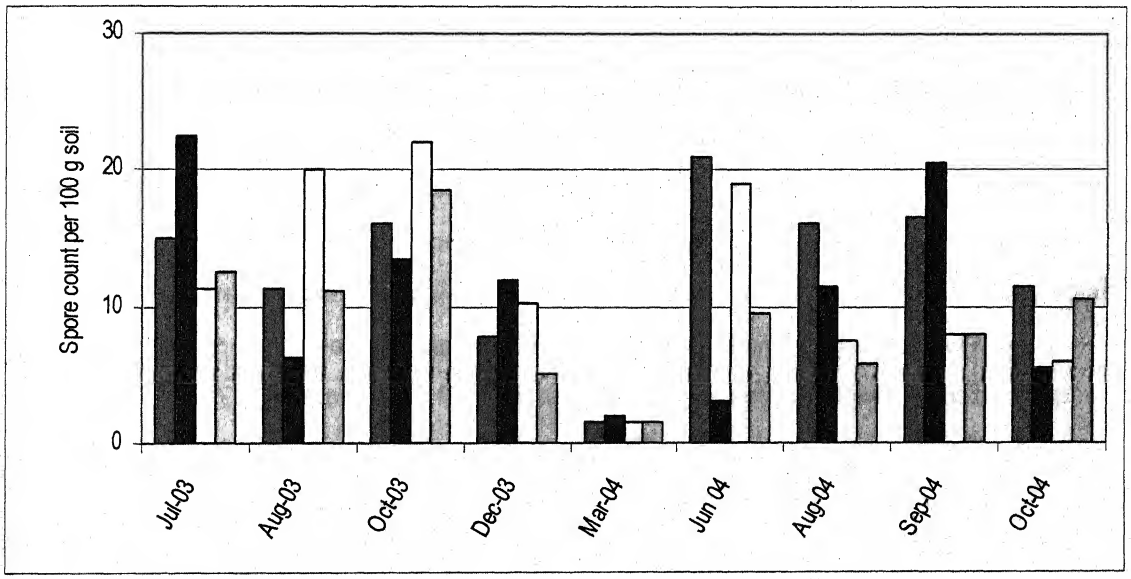
Date of sampling	VAM spore count per 100 g soil in rhizosphere of Aonla varieties				
	Chakaiya	Kanchan	Krishna	NA-7	Mean
July, 2003	15.0*	22.5	11.3	12.5	15.3
August, 2003	11.3	6.3	20.0	11.3	12.2
October, 2003	16.0	13.5	22.0	18.5	17.5
December, 2003	7.8	12.0	10.3	5.0	8.8
March, 2004	1.5	2.0	1.5	1.5	1.6
June, 2004	21.0	3.0	19.0	9.5	13.1
August, 2004	16.0	11.5	7.5	5.8	10.2
September, 2004	16.5	20.5	8.0	8.0	13.3
October, 2004	11.5	5.5	6.0	10.5	8.4
Mean	12.9	10.8	11.7	9.2	
		S. Em.±	C.D. (0.05%)		
Variety		1.2	NS		
Sampling date		1.7	4.9		
Variety * sampling date		3.5	9.7		

*Average of four replications

Table 4.3 VAM species composition in rhizosphere of different Aonla (*Emblica officinalis* Gaertn.) varieties during different periods

Date of sampling	Name of fungi	Spore count of VAM fungi in rhizosphere of				Total
		Chakaiya	Kanchan	Krishna	NA-7	
October, 2003	*Glomus* I	6	4	2	16	28
	Glomus II	2	14	14	10	40
	Acaulospora I	20	6	16	12	54
	Acaulospora II	2	6	2	10	20
	Gigaspora White	0	0	0	0	0
	Sub total	30	30	34	48	142
December, 2003	*Glomus* I	9	7	2	3	21
	Glomus II	2	0	5	2	9
	Acaulospora I	6	0	0	1	7
	Acaulospora II	0	2	7	2	11
	Gigaspora White	0	1	0	0	1
	Sub total	17	10	14	8	49
March, 2004	*Glomus* I	4	4	3	3	14
	Glomus II	0	0	0	0	0
	Acaulospora I	0	2	0	0	2
	Acaulospora II	0	0	2	0	2
	Gigaspora White	0	0	0	1	1
	Sub total	4	6	5	4	19
June, 2004	*Glomus* I	14	2	24	16	56
	Glomus II	4	2	0	0	6
	Acaulospora I	8	0	12	2	22
	Acaulospora II	6	2	6	4	18
	Gigaspora White	2	0	0	0	2
	Sub total	34	6	42	22	104
August, 2004	*Glomus* I	23	5	5	10	43
	Glomus II	4	2	0	2	8
	Acaulospora I	1	1	2	0	4
	Acaulospora II	1	0	3	0	4
	Gigaspora White	0	3	0	0	3
	Sub total	29	11	10	12	62
September, 2004	*Glomus* I	18	6	8	4	36
	Glomus II	6	18	4	2	30
	Acaulospora I	2	4	2	2	10
	Acaulospora II	0	0	0	0	0
	Gigaspora White	2	0	0	2	4
	Sub total	28	28	14	10	80
October, 2004	*Glomus* I	16	6	4	10	36
	Glomus II	6	4	0	4	14
	Acaulospora I	2	0	0	4	6
	Acaulospora II	0	0	2	0	2
	Gigaspora White	0	0	0	0	0
	Sub total	24	10	6	18	58
	Total	166	101	125	122	514





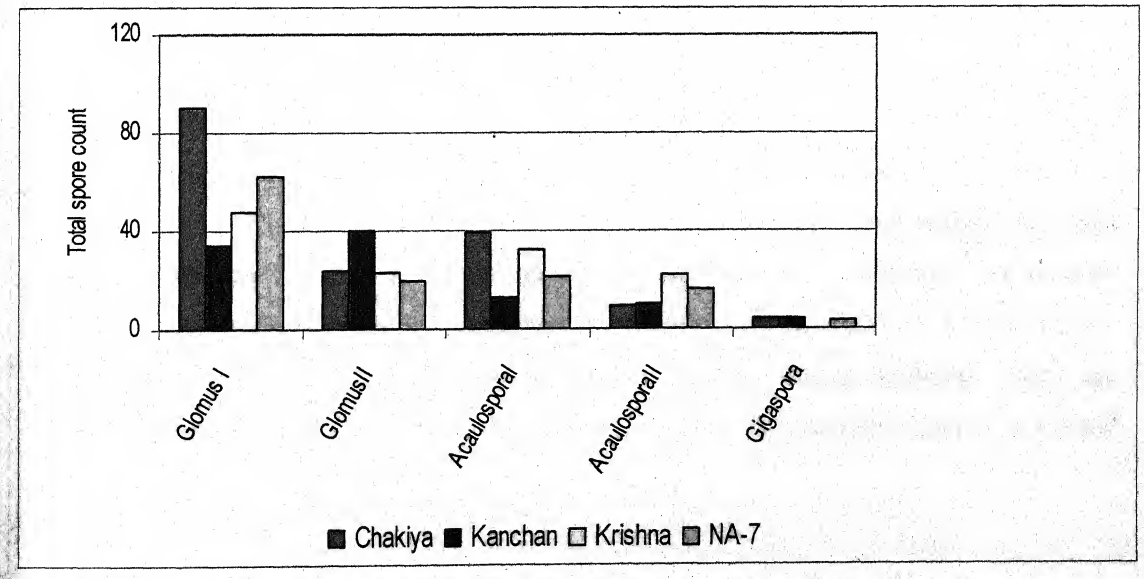


Fig.4. 1 Colonization-index, spore count and species composition of VAM fungi in rhizosphere of different Aonla(*Emblica officinalis* Gaertn.) varieties

rhizosphere of different varieties were at par, which ranged from 10.8 to 12.9. Among different sampling dates, maximum spore count was recorded during October 2003 (17.5 per 100 gm soil), followed by July 2003 (15.3 per 100 gm soil), September 2004 (13.3 per 100 gm soil) and June 2004 (13.1 per 100 gm soil), which were at par. The count during August 2003, August 2004, December 2003, and October 2004, were 12.2, 10.2, 8.8, and 8.4 spores per 100 gm soil, respectively and these were at par with count obtained during September 2004. The poorest count was obtained during March 2004 (1.6 per 100 gm soil). In general, the counts were directly related to soil moisture content, and it was more during rainy season than during drier periods.

VAM species composition in rhizosphere of different Aonla varieties are presented in Table 4.3. Five species belonging to three genera namely, *Glomus, Acaulospora* and *Gigaspora,* were common. Maximum total spore count was recorded for *Glomus* I (234), followed by *Glomus* II (107), *Acaulospora* I (105), and *Acaulospora* II (52). The poorest spore count was recorded for *Gigaspora* (11). Among different Aonla varieties, maximum total spore count was recorded in Chakaiya (166), followed by Krishna (125), NA-7 (122), and Kanchan (101). Among different sampling dates, maximum spore count was recorded during October 2003 (142), followed by June 2004 (104), September 2004 (80), August 2004 (62), October 2004 (58), March 2004 (56), and December 2003 (49). In general, *Glomus* I and *Glomus* II were predominant VAM species in rhizosphere of tested Aonla plants, followed by two *Acaulospora* species. A few spores of a whitish green *Gigaspora* species and a *Scutellospora* species were also recorded (Fig. 4.1). The better counts were recorded during rainy seasons than during drier periods.

4.1.2 Colonization index, spore count and species composition in Aonla variety Krishna under water-logged and normal conditions: The data on colonization index in rhizosphere of Aonla variety Krishna under water logged (during rainy season) and normal conditions during different dates are presented in Table 4.4. Colonization index was significantly superior in upland

Table 4.4 Colonization index and spore count of VAM fungi in rhizosphere of Aonla (*Emblica officinalis* Gaertn.) variety Krishna under water-logged and normal conditions during different sampling periods

Date of sampling	Colonization index in			VAM spore count per 100 g soil in		
	Upland plants	Lowland plants	Mean	Upland plants	Lowland plants	Mean
July, 2003	12.3 (20.5)	5.6 (13.6)	8.6 (17.0)	11.3	8.8	10.0
August, 2003	14.9 (22.7)	7.1 (15.4)	10.8 (19.1)	20.0	7.5	13.8
October, 2003	13.8 (21.8)	12.1 (20.3)	12.9 (21.0)	22.0	11.5	16.8
December, 2003	24.6 (29.7)	16.5 (23.9)	20.4 (26.8)	10.3	4.8	7.5
March, 2004	32.4 (34.7)	20.2 (26.60)	26 (30.6)	1.5	3.0	2.2
June, 2004	31.1 (33.9)	28 (31.9)	29.5 (32.9)	17.8	2.0	9.9
August, 2004	17.5 (24.7)	14.1 (22.0)	15.7 (23.3)	7.5	9.8	8.6
September, 2004	38.6 (38.4)	15.7 (23.3)	26.4 (30.9)	8.0	13.0	10.5
October, 2004	23.4 (28.9)	9.2 (17.6)	15.6 (23.2)	6.0	5.5	5.8
Mean	22.7 (28.4)	13.6 (21.6)		11.6	7.3	
	S. Em.±	C.D. (0.05%)		S. Em.±	C.D. (0.05%)	
Location	0.9	2.6		1.3	3.7	
Date of sampling	2.0	5.6		2.8	7.9	
Location * date of sampling	2.8	7.9		3.9	11.1	

*Average of four replications

Figures in parenthesis indicate angular transformation values

Table 4.5 VAM species composition in rhizosphere of upland and lowland Aonla (*Emblica officinalis* Gaertn.) plants recorded at different sampling periods

Date of sampling	Name of fungi	Spore count of VAM fungi in rhizosphere of		Total
		Upland plants	Lowland plants	
October, 2003	*Glomus* I	2	2	4
	Glomus II	14	4	18
	Acaulospora I	16	2	18
	Acaulospora II	2	0	2
	Sub Total	34	8	42
December, 2003	*Glomus* I	2	2	4
	Glomus II	5	1	6
	Acaulospora I	0	0	0
	Acaulospora II	7	0	7
	Sub Total	14	3	17
March, 2004	*Glomus* I	3	6	9
	Glomus II	0	0	0
	Acaulospora I	0	0	0
	Acaulospora II	2	0	2
	Sub Total	5	6	11
June, 2004	*Glomus* I	24	2	26
	Glomus II	0	3	3
	Acaulospora I	12	0	12
	Acaulospora II	6	0	6
	Sub Total	42	5	47
August, 2004	*Glomus* I	5	12	17
	Glomus II	0	4	4
	Acaulospora I	2	0	2
	Acaulospora II	3	1	4
	Sub Total	10	17	27
September, 2004	*Glomus* I	8	12	20
	Glomus II	4	4	8
	Acaulospora I	2	0	2
	Acaulospora II	0	0	0
	Sub Total	14	16	30
October, 2004	*Glomus* I	4	0	4
	Glomus II	0	6	6
	Acaulospora I	0	0	0
	Acaulospora II	2	0	2
	Sub Total	6	6	12
	Grand Total	125	61	186

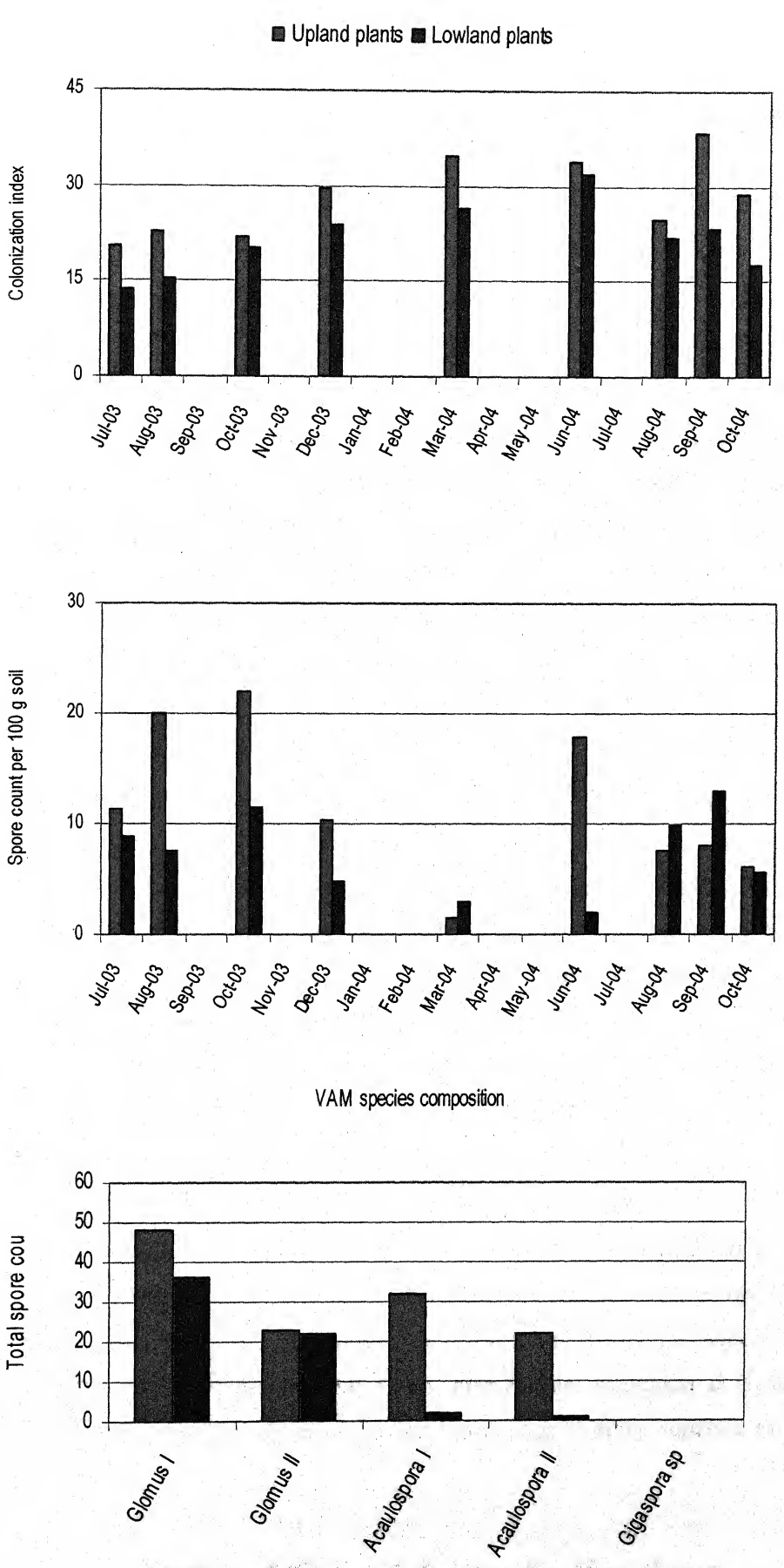


Fig. 4.2 Colonization index, spore count and species composition of VAM fungi in Aonla (*Emblica officinalis* Gaertn.) variety Krishna under water logged and normal

plants (22.7%) as compared to water logged plants (13.6%). Among different sampling dates, maximum colonization-index was recorded during June 2004 (29.5%), followed by September 2004 (26.4%), March 2004 (26.0%), which were at par. The index values during December 2003 (20.4%), August 2004 (15.7%), and October 2004 (15.6%) were at par. The poorest colonization index was recorded in October 2003 (12.9%), August 2003 (10.8%) and July 2003 (8.6%). As already indicated the colonization-index values were more during dry sampling periods as compared to rainy season. The data on spore count per 100 g soil in rhizosphere of Aonla varieties Krishna under water logged and normal conditions are presented in Table 4.4. The spore population per 100 g soil of AM fungi was significantly more in upland plants (11.6) than in lowland plants (7.3). Among different sampling dates, maximum spore count was recorded during October 2003 (16.8), followed by August 2003 (13.8), September 2004 (10.5), July 2003 (10.0), June 2004 (9.9), August 2004 (8.6) and December 2003 (7.5), which were at par. The poorest counts were obtained during October 2004 (5.8) and March 2004 (2.2), which were at par. The data on VAM species composition in rhizosphere of Aonla varieties Krishna under water logged and normal conditions are presented in Table 4.5. *Glomus* I (84) recorded maximum total spore count, followed by *Glomus* II (45), *Acaulospora* I (34) and *Acaulospora* II (23). Total spore count was more in upland plants (125) than lowland plants (61). Among different sampling dates, maximum spore count was recorded during June 2004 (47), followed by October 2003 (42), September 2004 (30), August 2004 (27), December 2003 (17). The lowest spore counts were recorded in October 2004 (12) and March 2004 (11).

4.1.3 Colonization index, spore count and species composition in Aonla rhizosphere variety NA-7 with and without wheat as an intercrop: Data on colonization index and spore count per 100 g soil in Aonla rhizosphere variety NA-7 with and without wheat as an intercrop are presented in Table 4.6. During crop period, colonization index was significantly superior in Aonla

Table 4.6 Colonization index and spore count of VAM fungi in rhizosphere of Aonla variety NA-7 with and without wheat as inter-crop

Date of sampling	Colonization index in Aonla			VAM spore count per 100 g soil in rhizosphere of Aonla		
	With wheat	Without wheat	Mean	With wheat	Without wheat	Mean
Pre crop period						
July, 2003	27.8* (31.8#)	27.5 (31.6)	27.7 (31.7)	22.5*	12.5	17.5
August, 2003	17.6 (24.8)	23.8 (29.2)	20.7 (27.0)	8.8	10.0	9.4
October, 2003	10.8 (20.1)	12.5 (20.7)	12.2 (20.4)	37.5	38.0	37.8
Mean	18.7 (25.6)	20.9 (27.2)		22.9	20.2	
Crop period						
December, 2003	36.6 (37.2)	22.2 (28.1)	29.2 (32.7)	19.0	12.8	15.9
March, 2004	40.2 (39.3)	26.9 (31.2)	33.4 (35.3)	2.5	2.5	2.5
Mean	38.4 (38.3)	24.6 (29.7)		10.8	7.6	
Post crop period						
June, 2004	23.0 (28.6)	26.4 (30.9)	24.7 (29.8)	35.5	29.5	32.5
August, 2004	31.0 (33.8)	22.4 (28.2)	26.6 (31.0)	17.8	21.0	19.4
September, 2004	23.1 (28.7)	28.3 (32.1)	25.6 (30.4)	8.5	8.5	8.5
October, 2004	18.4 (25.4)	20.4 (26.8)	19.4 (26.1)	12.5	15.5	14.0
Mean	23.7 (29.1)	24.3 (29.5)		18.6	18.6	

	S. Em.±	C.D. (0.05%)	S. Em.±	C.D.(0.05%)
Pre-crop period				
Treatment	1.8	NS	3.7	NS
Date of sampling	2.2	6.7	4.6	13.6
Treatment*date of sampling	3.2	NS	6.5	NS
Crop period				
Treatment	2.4	7.5	1.8	NS
Date of sampling	2.4	NS	1.8	5.5
Treatment*date of sampling	3.5	NS	2.5	NS
Post crop period				
Treatment	2.3	NS	2.2	NS
Date of sampling	3.2	NS	3.0	8.9
Treatment*date of sampling	4.5	NS	4.3	NS

*Average of four replications

Figures in parenthesis indicate angular transformation values

Table 4.7 VAM species composition in rhizosphere of Aonla (*Emblica officinalis* Gaertn.) plants, grown with and without wheat as an inter-crop during different periods

Date of sampling	Name of fungi	Spore count of VAM fungi in Aonla rhizosphere grown		Total
		With wheat	Without wheat	
Pre crop period				
October, 2003	*Glomus* I	34	64	98
	Glomus II	52	38	90
	Acaulospora I	6	4	10
	Acaulospora II	6	0	6
	Gigaspora white	0	6	6
	Sub total	98	112	210
Crop period				
December, 2003	*Glomus* I	26	12	38
	Glomus II	2	18	20
	Acaulospora I	1	1	2
	Acaulospora II	0	0	0
	Gigaspora white	1	6	7
	Sub total	30	37	67
March, 2004	*Glomus* I	6	6	12
	Glomus II	0	1	1
	Acaulospora I	0	0	0
	Acaulospora II	0	0	0
	Gigaspora white	0	3	3
	Sub total	6	10	16
Post crop period				
June, 2004	*Glomus* I	48	50	98
	Glomus II	20	14	34
	Acaulospora I	6	2	8
	Acaulospora II	4	4	8
	Gigaspora white	8	6	14
	Sub total	86	76	162
August, 2004	*Glomus* I	25	30	55
	Glomus II	5	0	5
	Acaulospora I	3	2	5
	Acaulospora II	0	0	0
	Gigaspora white	0	0	0
	Sub total	33	32	65
September, 2004	*Glomus* I	8	8	16
	Glomus II	0	4	4
	Acaulospora I	0	0	0
	Acaulospora II	0	0	0
	Gigaspora white	0	0	0
	Sub total	8	12	20
October, 2004	*Glomus* I	16	14	30
	Glomus II	8	0	8
	Acaulospora I	4	4	8
	Acaulospora II	0	0	0
	Gigaspora white	0	10	10
	Sub total	28	28	56
	Total	289	307	596

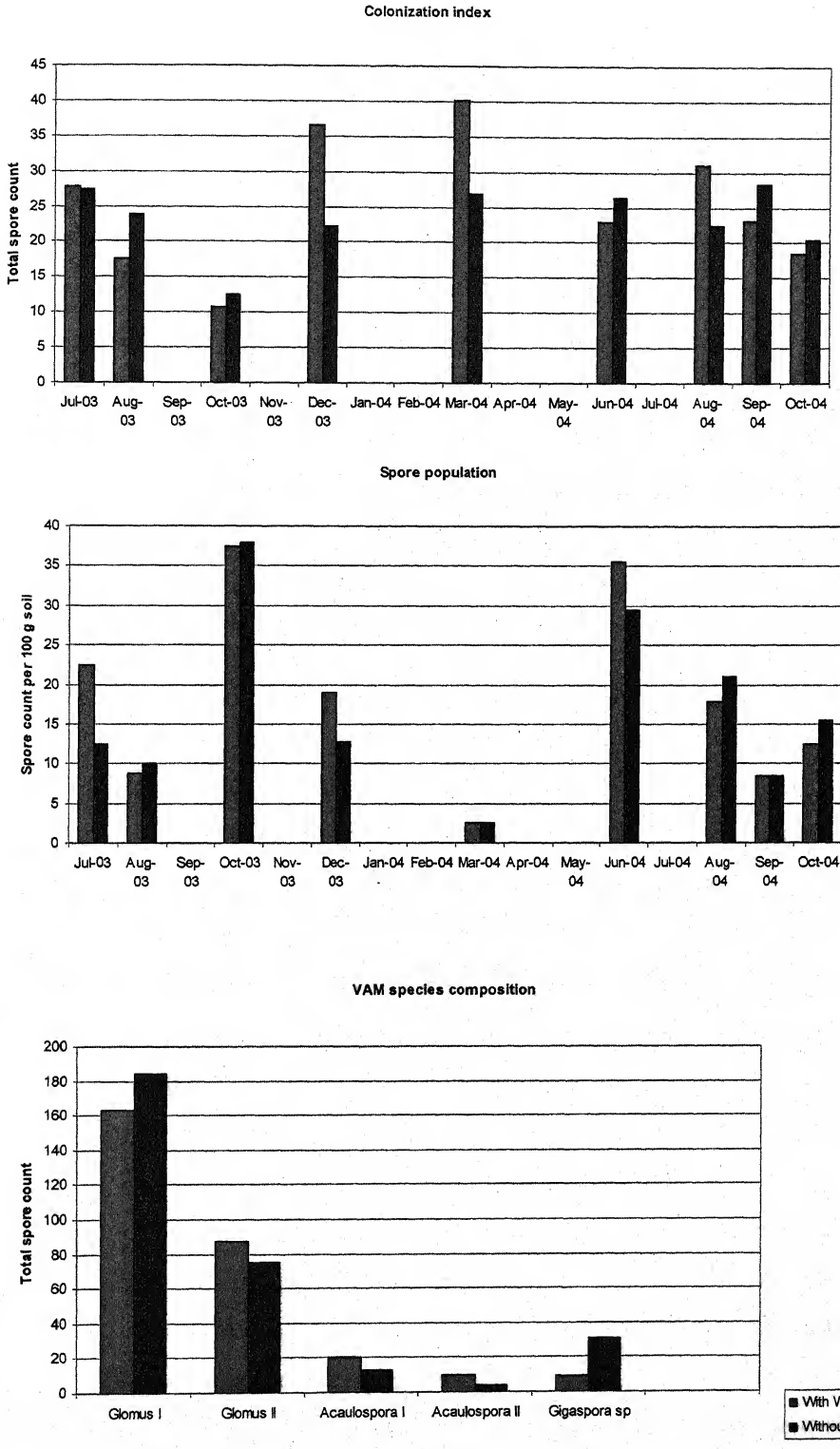


Fig. 4.3 Colonization index, spore count and species composition of VAM fungi in rhizosphere of Aonla (*Emblica officinalis* Gaertn.) variety NA-7 with and without wheat as an intercrop

plants with wheat (38.4%) than in Aonla plants grown without wheat (24.6%). While during pre- crop and post- crop periods, it was at par in both treatments i.e. with wheat (18.7%, 23.7%) and without wheat (20.9%, 24.3%), respectively. The observations on VAM spore count per 100 g soil from rhizosphere of Aonla plants grown with wheat were at par with respective observations on Aonla plants grown without wheat, during all above mentioned crop periods. The data on VAM species composition in Aonla rhizosphere variety NA-7 with and without wheat as an intercrop are presented in Table 4.7. *Glomus* I (347) recorded maximum total spore count, followed by *Glomus* II (162), *Gigaspora* (40), *Acaulospora* I (33) and *Acaulospora* II (14). Total spore count was slightly less in agroforestry plot (289) than control plot (307). Among different sampling dates, maximum spore count was recorded during October 2003 (210), followed by June 2004 (162), December 2003 (67), August 2004 (65), October 2004 (56) and September 2004 (20). The lowest spore count was recorded in March 2004 (16). Thus, the results showed that VAM species composition did not show any qualitative changes, however some quantitative changes in species composition were recorded (Fig. 4.3).

4.1.4 Colonization index, spore count and species composition in rhizosphere of Ber varieties: The data on colonization index in rhizosphere of Ber varieties recorded during different seasons are presented in Table 4.8. Maximum colonization index was recorded in Banarsi karaka (32.1%) and Seo (32.1%), followed by Ghot (30.0%), Makor (28.6%), Jharberi (28.1%) and Desi (27.8%). The poorest index value was recorded in Gola (24.3%). However, the difference in the colonization index of different Ber varieties were non-significant. Among different sampling dates, September 2004 (32.1%) recorded maximum colonization-index, followed by March 2005 (31.6%), June 2005 (30.8%) and July 2004 (29.5%), which were at par. The poorest colonization-index was recorded during October 2004 (21.5%), which was significantly less than above mentioned treatments. The data on spore

Table 4.8 Colonization index and VAM spore counts in different Ber (*Zizyphus mauritiana* Lamk.) varieties and its wild relatives.

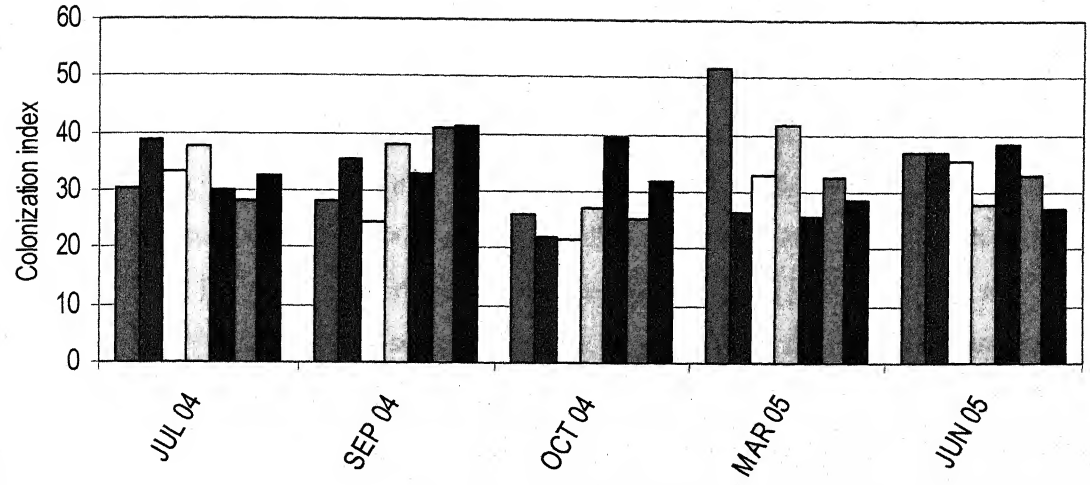
Date of sampling	Colonization index and VAM spore counts in							Mean
	Banarasi Karaka	Gola	Seo	Desi	Ghot	Jharberi	Makor	
Colonization index								
July, 2004	25.3* (30.2#)	30.0 (33.2)	37.4 (37.7)	39.1 (38.7)	24.9 (29.9)	22.4 (28.2)	28.8 (32.4)	29.5 (32.9)
September, 2004	22.1 (28.0)	17.2 (24.5)	38.3 (38.2)	33.6 (35.4)	29.7 (33.0)	43.1 (41.0)	43.8 (41.4)	32.1 (34.5)
October, 2004	19.0 (25.8)	13.5 (21.5)	20.8 (27.1)	13.9 (21.9)	40.5 (39.5)	18.4 (25.4)	28.0 (31.9)	21.5 (27.6)
March, 2005	61.5 (51.6)	29.9 (33.1)	44.5 (41.8)	19.7 (26.3)	18.6 (25.5)	28.9 (32.5)	23.1 (28.7)	31.6 (34.2)
June, 2005	36.3 (37.0)	33.6 (35.4)	21.8 (27.8)	36.1 (36.9)	38.5 (38.3)	29.7 (33.0)	20.9 (27.2)	30.8 (33.7)
Mean	32.1 (34.5)	24.3 (29.5)	32.1 (34.5)	27.8 (31.8)	30.0 (33.2)	28.1 (32.0)	28.6 (32.3)	
Spore count per 100 g soil								
July, 2004	104.5*	66.0	42.5	57.0	82.0	58.0	44.0	64.9
September, 2004	16.0	26.0	17.0	17.5	18.5	13.0	19.5	18.2
October, 2004	11.5	7.0	5.0	9.5	21.5	15.5	15.5	12.2
March, 2005	4.0	5.5	6.5	5.0	11.5	19.5	15.5	10.0
June, 2005	11.5	24.5	5.5	7.0	10.5	6.0	10.5	10.8
Mean	29.5	25.8	15.3	19.2	28.8	22.4	21.0	

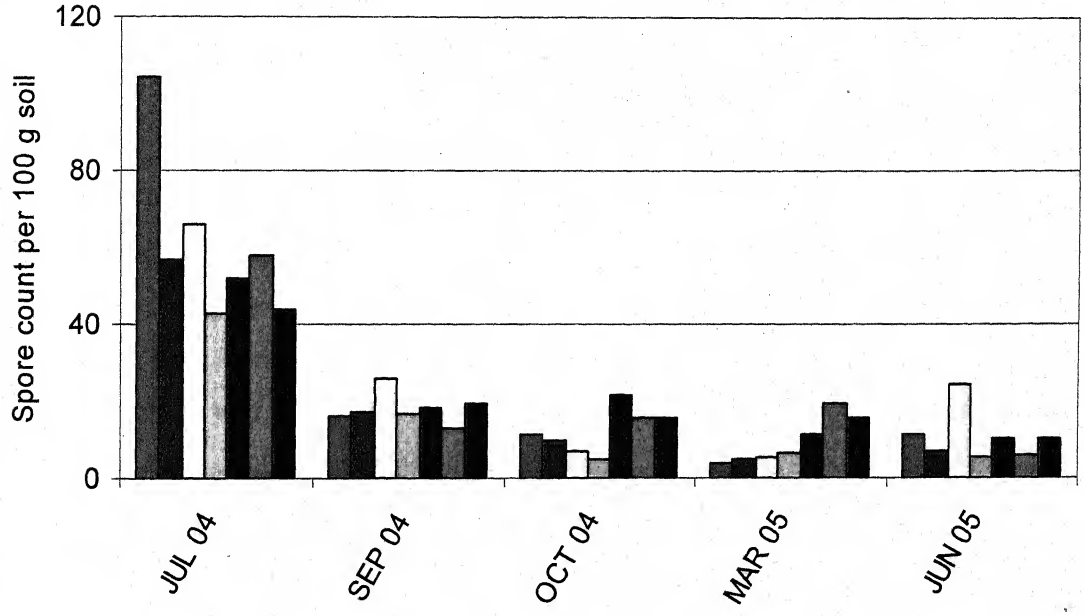
	Colonization index		Spore population	
	S. Em.±	C.D. (0.05%)	S. Em.±	C.D. (0.05%)
Variety	1.8	NS	3.4	10.0
Date of sampling	1.5	4.1	2.9	8.1
Date of sampling * variety	3.9	11.0	7.7	21.4

*Average of four replications.
#Figures in parenthesis indicate angular transformation values.

Table 4.9 VAM species composition in Ber (*Zizyphus mauritiana* Lamk.) rhizosphere at selected sites during different sampling periods

Date of sampling	VAM species	Spore count in Ber rhizosphere							
		Banarasi karaka	Desi	Gola	Seo	Ghot	Jharberi	Makor	Total
July, 2004	*Glomus* I	56	48	65	18	61	65	31	344
	Glomus II	1	0	0	2	0	3	1	7
	Glomus mosseae	0	0	0	0	3	0	0	3
	Acaulospora I	26	1	1	1	32	10	10	81
	Acaulospora II	1	3	0	1	1	1	0	7
	Gigaspora sp	0	0	0	0	3	6	0	9
	Sub total	84	52	66	22	100	85	42	451
September 2004	*Glomus* I	1	6	12	3	10	4	6	42
	Glomus II	3	8	3	5	4	4	6	33
	Glomus mosseae	0	0	0	0	0	0	0	0
	Acaulospora I	0	0	0	0	1	3	5	9
	Acaulospora II	1	0	3	2	4	2	3	15
	Gigaspora sp	0	0	0	0	0	0	0	0
	Sub total	5	14	18	10	19	13	20	99
October, 2004	*Glomus* I	2	2	2	2	7	5	13	33
	Glomus II	0	1	1	1	5	7	3	18
	Glomus mosseae	0	0	0	0	0	0	0	0
	Acaulospora I	0	0	0	0	7	1	1	9
	Acaulospora II	3	1	1	0	4	1	1	11
	Gigaspora sp	0	0	0	0	0	3	0	3
	Sub total	5	4	4	3	23	17	18	74
March, 2005	*Glomus* I	2	2	2	4	2	9	2	23
	Glomus II	0	0	0	0	2	9	2	13
	Glomus mosseae	0	0	0	0	0	0	0	0
	Acaulospora I	0	1	0	0	1	1	1	4
	Acaulospora II	0	0	0	1	0	2	1	4
	Gigaspora sp	0	0	0	0	0	0	0	0
	Sub total	2	3	2	5	5	21	6	44
June, 2005	*Glomus* I	12	2	20	2	0	0	18	54
	Glomus II	0	4	0	0	0	0	0	4
	Glomus mosseae	0	0	0	0	0	0	0	0
	Acaulospora I	0	10	44	4	16	12	2	88
	Acaulospora II	0	0	10	0	0	0	2	12
	Gigaspora sp	4	0	6	0	0	0	0	10
	Sub total	16	16	80	6	16	12	22	168
	Total	112	89	170	46	163	148	108	836





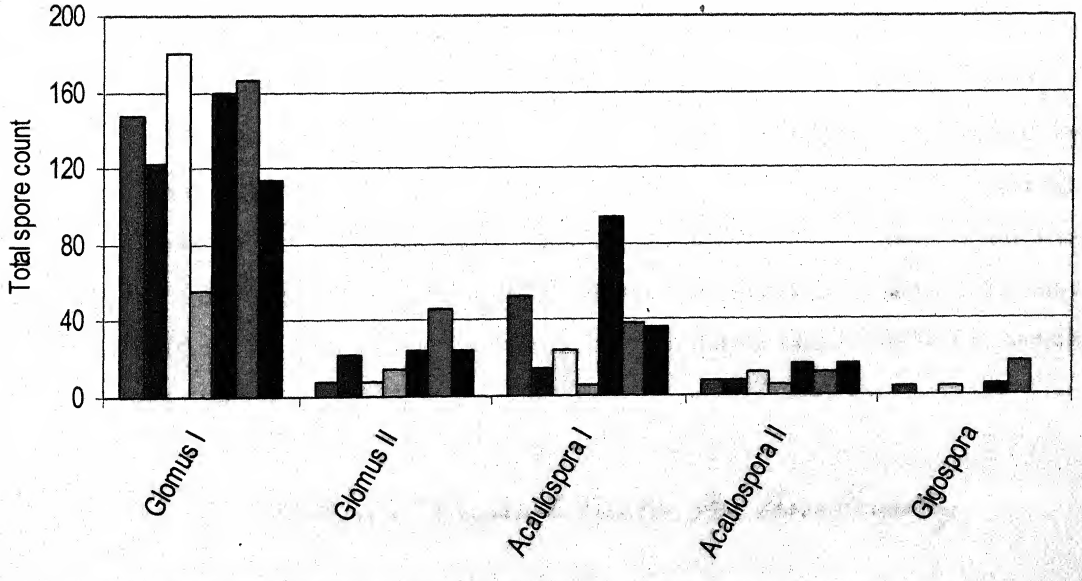


Fig.4.4 Colonization-index, spore count and species composition of VAM fungi in rhizosphere

count per 100 g soil in rhizosphere of Ber varieties are presented in Table 4.8. Maximum VAM spore count was recorded in Banarsi Karaka (29.5 per 100 g soil), followed by Ghot (28.8 per 100 g soil), Gola (25.8 per 100 g soil), Jharberi (22.4 per 100 g soil) and Makor (21.0 per 100 g soil), which were at par. The poorest spore count was recorded in Desi (19.2 per 100 g soil) and Seo (15.3 per 100 g soil) which were at par. Among different sampling dates, maximum spore count was recorded in July 2004 (64.9 per 100 g soil) which was significantly superior to other readings. The value during September 2004 (18.2 per 100 g soil), October 2004 (12.2 per 100 g soil), June 2005 (10.8 per 100 g soil), were at par. The lowest reading was recorded in March 2005 (10.0 per 100 g soil). VAM species composition in rhizosphere of different Ber varieties are presented in Table 4.9. Maximum total spore count was recorded for *Glomus* 1 (496), followed by *Acaulospora* 1 (191), *Glomus* II (75), *Acaulospora* II (49) and *Gigaspora* (11). The poorest spore count was recorded for *Glomus mosseae* (3). Among different Aonla varieties, maximum total spore count was recorded in Gola (170), followed by Ghot (163), Jharberi (148), Banarsi Karaka (112), Makor (108) and Desi (89). The poorest spore count was recorded for Seo (46). Among different sampling dates, maximum spore count was recorded during July 2004 (451), followed by June 2005 (168), September 2004 (99), October 2004 (74) and March 2005 (74).

4.1.5 Colonization index, spore count and species composition in rhizosphere of Chironji: The data on colonization index and spore count in rhizosphere of Chironji during different seasons are presented in Table 4.10. Differences in colonization index values at Jakhlon (27.0%) and Nilkanthh (18.9%) were non-significant. Among different sampling dates, maximum colonization index was recorded during June 2005 (29.0%), followed by March 2005 (23.1%), July 2004 (22.2%), and September 2004 (17.6%). However the differences were non-significant. Maximum spore count was recorded during July 2004 (19.5), followed by September 2004 (13.5), June 2005 (11.8). The poorest count was recorded during March 2005 (5.3), which

Table 4.10 Colonization index and count of VAM spores in rhizosphere of Chironji (*Buchanania lanzan* Spr.) at different sites

Date of sampling	Colonization index at			VAM spore count per 100 g soil at		
	Jakhlon	Nilkanthh	Mean	Jakhlon	Nilkanthh	Mean
July, 2004	35.1* (36.3#)	11.6 (19.9)	22.2 (28.1)	11	28	19.5
September, 2004	17.2 (24.5)	18.1 (25.2)	17.6 (24.8)	13	14	13.5
March, 2005	20.0 (26.6)	26.2 (30.8)	23.1 (28.7)	5.5	5	5.25
June, 2005	37.6 (37.9)	20.9 (27.2)	29.0 (32.6)	12.5	11	11.75
Mean	27.0 (31.3)	18.9 (25.8)		10.5	14.5	
	S.Em. ±	C.D. (0.05%)		S.Em. ±	C.D. (0.05%)	
Site	2.8	NS		1.9	NS	
Sampling date	3.9	NS		2.6	7.7	
Interaction	5.6	NS		3.7	NS	

*Average of four replications

Figures in parenthesis indicate angular transformation values

Table 4.11 VAM species composition in Chironji (*Buchanania lanzan* Spr.) rhizosphere at selected sites during different sampling periods

Date of sampling	VAM species	Spore count in Chironji rhizosphere		
		Jakhlon forest nursery	Nilkanthh temple	Total
July, 2004	*Glomus* I	3	26	29
	Glomus II	3	3	6
	Acaulospora I	0	2	2
	Acaulospora II	0	0	0
	Glomus mosseae	1	0	1
	Sub total	7	31	38
September, 2004	*Glomus* I	5	5	10
	Glomus II	3	7	10
	Acaulospora I	0	0	0
	Acaulospora II	0	0	0
	Gigaspora sp.	0	1	1
	Sub total	8	13	21
March, 2005	*Glomus* I	4	0	4
	Glomus II	1	2	3
	Acaulospora I	0	0	0
	Acaulospora II	0	0	0
	Sub total	5	2	7
June, 2005	*Glomus* I	10	8	18
	Glomus II	4	6	10
	Acaulospora I	0	2	2
	Acaulospora II	0	2	2
	Sub total	14	18	32
	Total	34	64	98

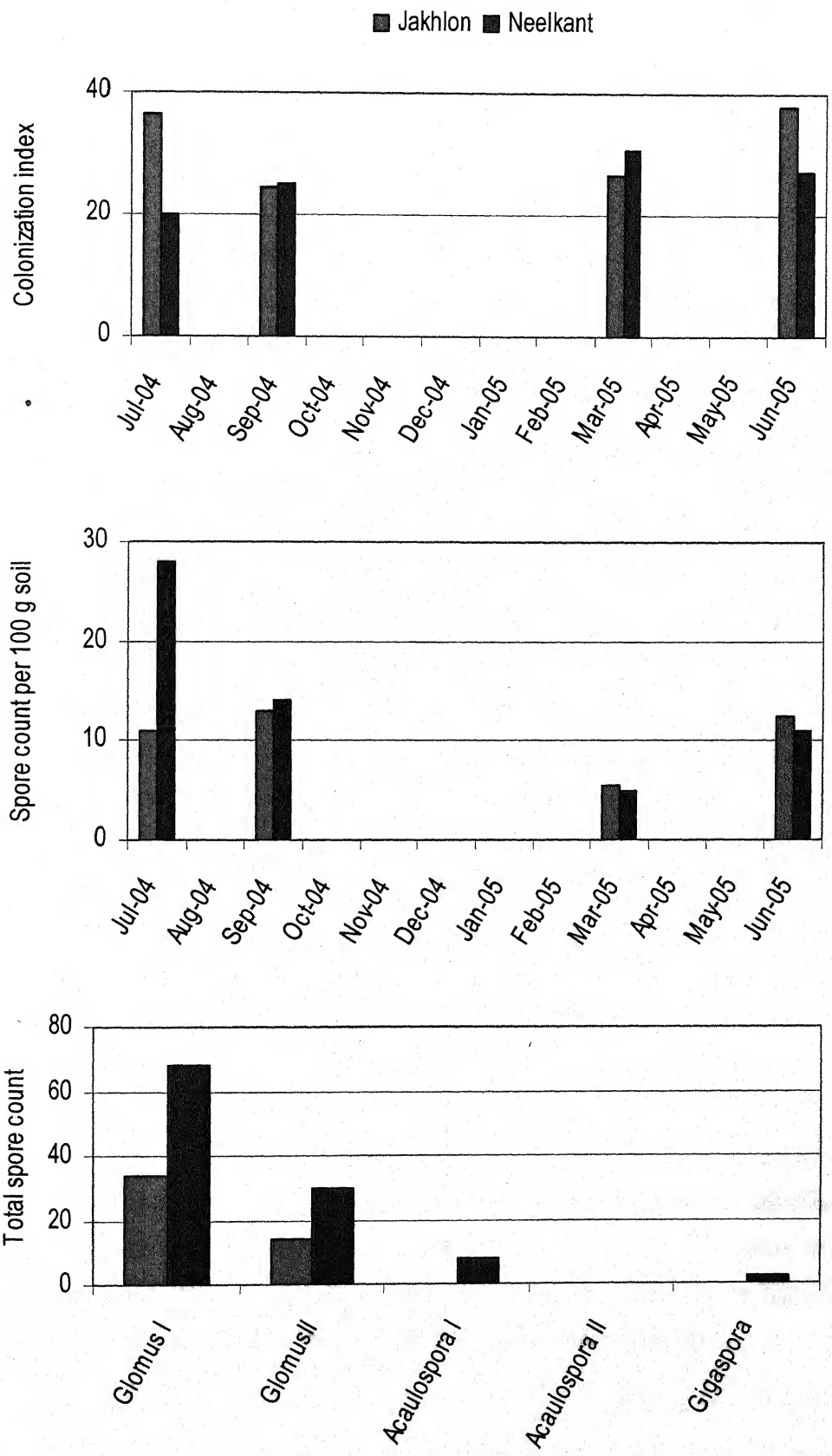


Fig. 4.5 Colonization-index, spore count and species composition of VAM fungi in rhizosphere of Chironji

was significantly less than September 2004 value. The data on species composition in Chironji recorded during different seasons are presented in Table 4.11. Maximum total spore count was recorded for *Glomus* 1 (61), followed by *Glomus* II (29), *Acaulospora* 1 (4) and *Acaulospora* II (2). The poorest counts were in *Gigaspora* (1) and *Glomus mosseae* (1). Total spore counts were 64 and 34 at Nilkanthh and Jakhlon, respectively. Among different dates, maximum spore count was in July 2004 (38), followed by June 2005 (32), September 2004 (21). The poorest spore count was during March 2005 (7).

4.1.6 Colonization index, spore count and species composition in Lasoda: The data on colonization index and spore count in Lasoda recorded during different seasons are presented in Table 4.12 and Fig. 4.6. Maximum colonization index was recorded at NRCAF, silvipasture site (32.9%), followed by NRCAF, block plantation and Nareta (16.9), which were at par. Among different sampling dates, maximum colonization index was recorded during June 2005 (27.2%), followed by September 2004 (25.0%), July 2004 (23.1%) and October 2004 (22.1%). The poorest index was recorded in March 2005 (21.6%). However, the differences were non-significant. Maximum spore count was recorded during July 2004 (27.6), followed by September 2004 (11.8) and June 2005 (8.9). The poorest count was recorded during March 2005 (3.5). The data on species composition in rhizosphere of Lasoda recorded during different seasons are presented in Table 4.13. Maximum total spore count was recorded for *Glomus* 1 (75), followed by, *Glomus* II (36) and *Acaulospora* 1 (24). Poorest total count was in *Acaulospora* II (1) and *Gigaspora* (1). Among different Lasoda sites, maximum spore count was recorded in NRCAF, block plantation (77), followed by NRCAF, silvipasture site (60) and Nareta village (0). Maximum spore count was recorded in October 2004 (39) among different sampling dates, followed by July 2004 (38), September 2004 (34), June 2005 (22) and March 2005 (4).

Table 4.12 Colonization index and count of VAM spores in rhizosphere of Lasoda (*Cordia myxa* Roxb.)at different sites

Date of sampling	Colonization index in				Spore count per 100 g soil in			
	Nareta	NRCAF Block plantation	NRCAF Silvi-pasture	Mean	Nareta	NRCAF Block plantation	NRCAF Silvi-pasture	Mean
July, 2004	13.3 (21.4)	20.9 (27.2)	37.1 (37.5)	23.1 (28.7)	1.5	53.0	29.0	27.6
September, 2004	13.5 (21.6)	30.6 (33.6)	32.7 (34.9)	25.0 (30.0)	3.0	14.0	18.5	11.8
October, 2004	16.2 (23.7)	18.5 (24.7)	34.2 (35.8)	22.1 (28.1)	-	-	-	-
March, 2005	18.7 (25.6)	15.8 (23.4)	31.4 (34.1)	21.6 (27.7)	1.0	4.0	5.5	3.5
June, 2005	24.4 (29.6)	28.1 (32.0)	29.2 (32.7)	27.2 (31.4)	2.5	8.5	15.5	8.9
Mean	16.9 (24.3)	22.4 (28.2)	32.9 (35.0)		2.0	20.3	15.4	
		S.Em. ±	C.D. (0.05%)		S.Em. ±	C.D. (0.05%)		
Sites		1.7	4.8		3.5	10.1		
Sampling date		1.9	NS		4.1	11.6		
Interaction		3.8	NS		7.1	20.1		

*Average of four replications
Figures in parenthesis indicate angular transformation values

Table 4.13 VAM species composition in Lasoda (*Cordia myxa* Roxb.) rhizosphere at selected sites during different sampling periods

Date of sampling	VAM species	Spore count in Lasoda rhizosphere			
		Nareta, Datia	Field 1, NRC	Field 2, NRC	Total
July, 2004	*Glomus* I	0	23	5	28
	Glomus II	0	1	0	1
	Acaulospora I	0	7	1	8
	Acaulospora II	0	1	0	1
	Sub total	0	32	6	38
September, 2004	*Glomus* I	0	1	8	9
	Glomus II	0	9	10	19
	Acaulospora I	0	3	2	5
	Acaulospora II	0	0	0	0
	Gigaspora sp.	0	0	1	1
	Sub total	0	13	21	34
October, 2004	*Glomus* I	0	16	6	22
	Glomus II	0	7	7	14
	Acaulospora I	0	2	1	3
	Acaulospora II	0	0	0	0
	Sub total	0	25	14	39
March, 2005	*Glomus* I	0	3	1	4
	Glomus II	0	0	0	0
	Acaulospora I	0	0	0	0
	Acaulospora II	0	0	0	0
	Sub total	0	3	1	4
June, 2005	*Glomus* I	0	2	10	12
	Glomus II	0	0	2	2
	Acaulospora I	0	2	6	8
	Acaulospora II	0	0	0	0
	Sub total	0	4	18	22
	Total	0	77	60	137

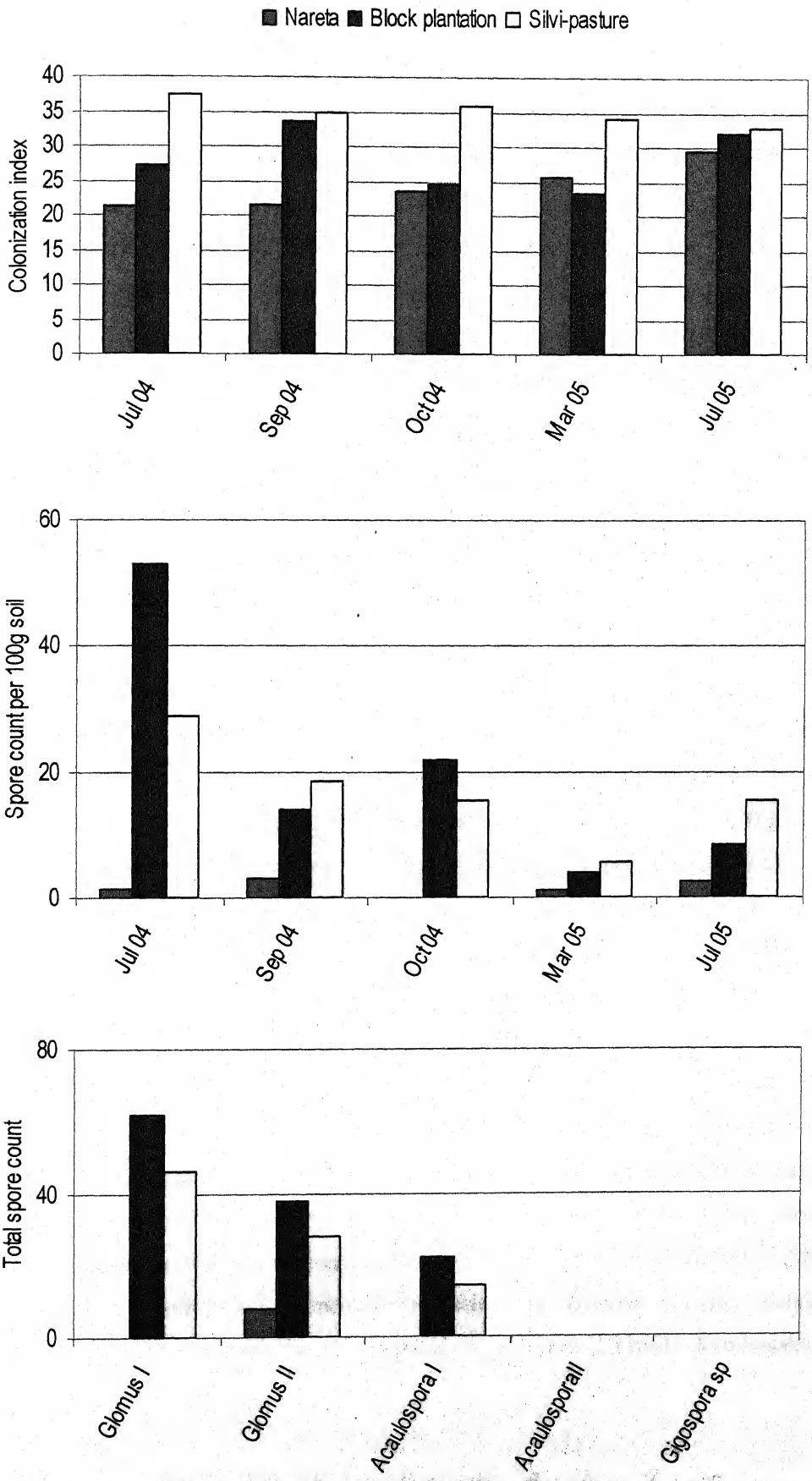


Fig.4.6 Colonization-index, spore count and species composition of VAM fungi in rhizosphere of Lasoda

4.2 Effect of soil types on VAM activity:

4.2.1 Effect of soil types on mycorrhization of Aonla rhizosphere by VAM fungi: The results on effect of soil on colonization index, in rhizosphere of Aonla are presented in Table 4.14. Maximum colonization index was recorded in black soil (24.1%), which was at par with lateritic soil (20.1%). The index was poorest in red soil (16.7%). Observation in black soil was significantly more than red soil. Among different sampling dates, maximum colonization-index was recorded during June 2004 (31.5%), followed by March 2004 (28.6%) and December 2003 (24.9%), which were at par. The index values during October 2004 (21.4%), August 2004 (20.5%), September 2004 (18.4%), October 2003 (15.3%) and August 2003 (15.3%) were at par. Poorest colonization index was recorded in July 2003 (11.6%). In general, the colonization-index was inversely proportional to soil moisture content and it was more during dry sampling periods as compared to wet periods of the year. The data on spore count per 100 g soil in rhizosphere of Aonla variety NA-7 in different soil types during different sampling periods are shown in Table 4.15. Maximum VAM spore count was recorded in lateritic soil (15.9 per 100 g soil), which was significantly superior to black soil (11.3 per 100 g soil). The poorest spore count was recorded in red soil (9.6 per 100 g soil). Among different sampling dates, maximum spore count was recorded in October 2003 (33.5), which was significantly more than other readings. The spore count per 100 gm soil during August 2004 (13.4), September 2004 (12.0), June 2004 (11.7), December 2003(11.1), October 2004 (9.7), July 2003 (8.3) and August 2003 (6.7) which were at par. The lowest reading was recorded in March 2004 (3.5). Maximum biological diversity for VAM fungi was recorded in lateritic soil as compared to other two tested soil types and the spore count was more during rainy seasons than other drier months. The data on VAM species composition of Aonla rhizosphere in three different soil types during different sampling periods are presented in Table 4.16. *Glomus* 1 (319) recorded maximum total spore count, followed by *Glomus* II (165), *Acaulospora* 1

(122), and *Acaulospora* II (106). The poorest spore count was recorded for *Gigaspora* (7). Among different soil types, maximum total spore count was recorded in lateritic soil (376), followed by black soil (221) and red soil (122). Among different sampling dates, maximum spore count was recorded during October 2003 (320), followed by June 2004 (83), August 2004 (76), December 2003 (74). September 2004 (72), October 2004 (66) and March 2004 (28). In general, better counts were recorded during rainy seasons as compared to drier months. The data on pH, EC and percent organic content of soil samples taken from basins of Aonla (variety NA-7) growing in different soil types are presented table 4.17. Soil pH values in black soil, lateritic soil and red soil veried in narrow range (5.88 to 5.94). Maximum EC was recorded in black soil (49 μS cm^{-1}), followed by lateritic soil (39 μS cm^{-1}) and red soil (38 μS cm^{-1}). Maximum percent organic content was recorded in black soil (1.53 %), followed by red soil (1.20 %) and Lateritic soil (1.90 %). Detailed information on soil pH, EC and percent organic content of all marked trees is presented in appendix V.

4.2.2 Effect of soil moisture and soil temperature: Results on effect of soil moisture, soil surface temperature and soil temperature at 10 cm depth during summer months on colonization index of Aonla in different soil types are shown in Table 4.18. Maximum colonization was recorded in lateritic soil (27.9%), which was significantly more than colonization in red (21.2%) and black soils (17.9%). The index significantly increased from March 2005 (21.9%) to April 2005 (27.4%), significantly reduced from April 2005 to May 2005 (19.3%) and the observations during May 2005 and June 2005 (22.0%) were at par. In black soil, observations on colonization index during different months remained at par. In lateritic soil, the index values, significantly increased from March 2005 to April 2005 then significantly decreased from April 2005 to May 2005 and were at par during May 2005 and June 2005. The trend in red soil was similar to lateritic soil except that the value was significantly more during June 2005 than May 2005 value. Maximum soil

Table 4.14 Colonization index of VAM fungi in Aonla (*Emblica officinalis* Gaertn.) variety NA-7 in different soil types during different sampling periods

Date of sampling	Colonization index in			
	Black soil	Lateritic soil	Red soil	Mean
July,	13.6	9.3	12.3	11.6
2003	(21.6#)	(17.7)	(20.5)	(19.9)
August,	16.3	19	10.2	15
2003	(23.8)	(25.8)	(18.6)	(22.7)
October,	17	16.5	12.5	15.3
2003	(24.3)	(23.9)	(20.7)	(23.0)
December,	26.1	24.6	24.6	24.9
2003	(30.7)	(29.7)	(29.7)	(29.9)
March,	25.2	34.1	27	28.6
2004	(30.1)	(35.7)	(31.3)	(32.3)
June,	47.8	21.7	26.3	31.5
2004	(43.7)	(27.7)	(30.8)	(34.1)
August,	29.7	14.2	18.8	20.5
2004	(33.0)	(22.1)	(25.7)	(26.9)
September,	13.7	25.3	17.1	18.4
2004	(21.7)	(30.2)	(24.4)	(25.4)
October,	32.4	20.7	12.7	21.4
2004	(34.7)	(27.0)	(20.8)	(27.5)
Mean	24.1	20.1	16.7	
	(29.4)	(26.6)	(24.7)	
		S. Em. ±	C.D. (0.05 %)	
Soil type		1.1	3.1	
Sampling date		1.9	5.4	
Soil type * sampling date		3.3	9.3	

*Average of four replications

Figures in parenthesis indicate angular transformation values

Table 4.15 Spore count of VAM fungi in rhizosphere of Aonla (*Emblica officinalis* Gaertn.) variety NA-7 in different soil types during different sampling periods

Date of sampling	VAM spore count per 100 g soil in			
	Black soil	Lateritic soil	Red soil	Mean
July, 2003	2.5*	10.0	12.5	8.3
August, 2003	2.5	3.8	13.8	6.7
October, 2003	40.0	42.0	18.5	33.5
December, 2003	13.3	15.8	4.3	11.1
March, 2004	5.5	3.5	1.5	3.5
June, 2004	3.0	22.5	9.5	11.7
August, 2004	16.5	18.0	5.8	13.4
September, 2004	13.5	14.5	8.0	12.0
October, 2004	5.0	13.5	10.5	9.7
Mean	11.3	15.9	9.6	
		S. Em. ±	C.D. (0.05 %)	
Soil type		1.5	4.4	
Sampling date		2.7	7.6	
Soil type * sampling date		4.6	13.1	

*Average of four replications

Table 4.16 VAM species composition of Aonla (*Emblica officinalis* Gaertn.) rhizosphere in three different soil types during different sampling period

Date of sampling	Name of fungi	Spore count of VAM fungi in rhizosphere of Aonla in			Total
		Black soil	Lateritic soil	Red soil	
October, 2003	*Glomus* I	32	64	16	112
	Glomus II	50	38	10	98
	Acaulospora I	10	36	12	58
	Acaulospora II	10	32	10	52
	Gigaspora white	0	0	0	0
	Sub total	102	170	48	320
December, 2003	*Glomus* I	8	10	3	21
	Glomus II	9	4	2	15
	Acaulospora I	0	10	1	11
	Acaulospora II	12	13	2	27
	Gigaspora white	0	0	0	0
	Sub total	29	37	8	74
March, 2004	*Glomus* I	9	8	3	20
	Glomus II	3	0	0	3
	Acaulospora I	0	1	0	1
	Acaulospora II	1	2	0	3
	Gigaspora white	0	0	1	1
	Sub total	13	11	4	28
June, 2004	*Glomus* I	4	32	16	52
	Glomus II	0	4	0	4
	Acaulospora I	0	12	2	14
	Acaulospora II	1	4	4	9
	Gigaspora white	0	4	0	4
	Sub total	5	56	22	83
August, 2004	*Glomus* I	16	16	10	42
	Glomus II	16	7	2	25
	Acaulospora I	0	4	0	4
	Acaulospora II	0	5	0	5
	Gigaspora white	0	0	0	0
	Sub total	32	32	12	76
September, 2004	*Glomus* I	20	16	4	40
	Glomus II	2	8	2	12
	Acaulospora I	4	4	2	10
	Acaulospora II	2	6	0	8
	Gigaspora white	0	0	2	2
	Sub total	28	34	10	72
October, 2004	*Glomus* I	8	14	10	32
	Glomus II	2	2	4	8
	Acaulospora I	0	20	4	24
	Acaulospora II	2	0	0	2
	Gigaspora white	0	0	0	0
	Sub total	12	36	18	66
	Grant Total	221	376	122	719

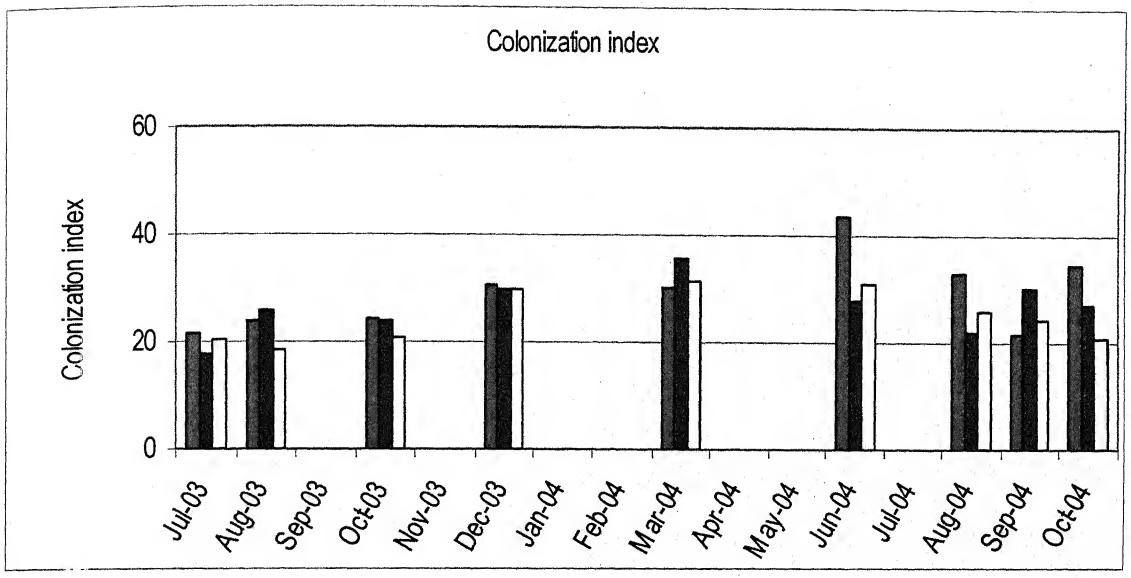
Table 4.17 Soil pH, EC and percent organic content of the soil samples taken from basins of Aonla (varieties NA-7) growing in different soil types

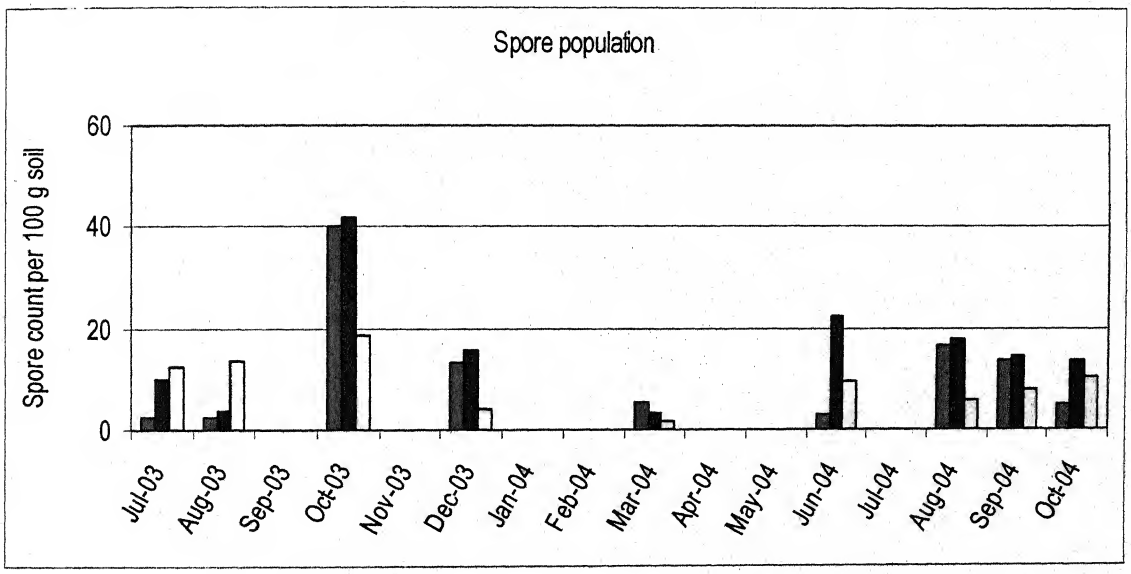
Soil type	pH		EC (μS cm^{-1})		% OC	
	Mean	Range	Mean	Range	Mean	Range
Black soil	5.88	5.26-6.32	49	28-61	1.53	0.78 – 2.74
Lateritic soil	5.93	5.57-6.44	39	33-49	1.19	0.91 – 1.40
Red soil	5.94	5.75-6.12	38	33-49	1.20	1.09 – 1.42

Table 4.18 Colonization index of Aonla roots, soil moisture, soil surface temperature and soil temperature at 10 cm depth in three soil types during summer months

Sampling date	Colonization index of Aonla plants in				Soil moisture (%)			
	Black soil	Lateritic soil	Red soil	Mean	Black soil	Lateritic soil	Red soil	Mean
March, 2005	15.2* (23.0)#	29.3 (32.8)	18.3 (25.0)	21.9 (26.9)	-	-	-	-
April, 2005	17.4 (24.6)	39.1 (38.7)	27.1 (31.4)	27.4 (31.6)	5.6*	4.6	3.9	4.7
May, 2005	19.5 (26.2)	23.4 (29.0)	15.2 (23.0)	19.3 (26.1)	5.0	2.8	2.9	3.6
June, 2005	19.7 (26.3)	20.7 (27.1)	25.7 (30.4)	22.0 (28.0)	6.5	7.2	5.6	6.4
Mean	17.9 (25.0)	27.9 (31.9)	21.2 (27.5)		5.7	4.8	4.2	
		S. Em.±	C.D. (0.05%)			S. Em.±	C.D. (0.05%)	
Sampling date		1.4	4.0			0.3	0.9	
Soil type		1.2	3.4			0.3	0.9	
Interaction		2.4	6.9			0.6	NS	
	Soil temperature at 10 cm depth (°C)				Soil surface temperature (°C)			
April, 2005	36.0*	37.0	36.3	36.4	51.2*	46.6	41.3	46.4
May, 2005	45.3	46.8	46.8	46.3	73.5	70.2	70.2	71.4
June, 2005	44.3	44.5	44.3	44.3	60.5	59.9	58.0	59.4
Mean	41.8	42.8	42.4		61.7	59.0	56.5	
		S. Em.±	C.D. (0.05%)			S. Em.±	C.D. (0.05%)	
Sampling date		0.3	1.0			0.3	1.0	
Soil type		0.3	NS			0.3	1.0	
Interaction		0.5	NS			0.6	1.7	

* Average of four replications.
# Figures in the parenthesis indicate angular transformation values





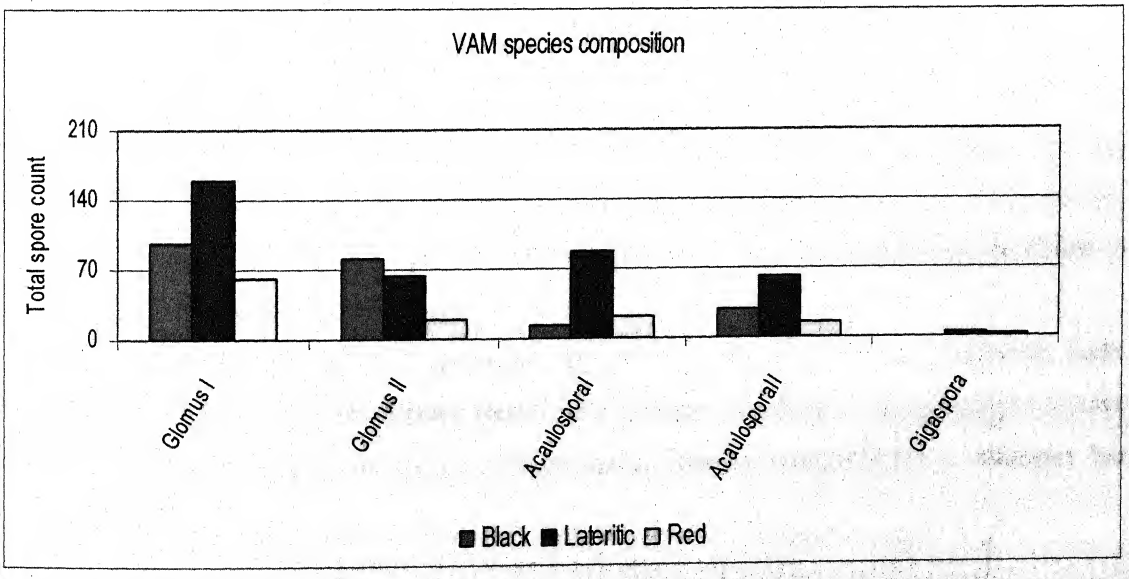


Fig. 4.7 Colonization-index, spore count and species composition of VAM fungi in Aonla variety NA-7 in different soil types during different sampling periods

moisture was recorded during June 2005 (6.4%), followed by April 2005 (4.7%) and May 2005 (3.6%). High values of soil moisture during June 2005 were due to rains just before sampling date. Among different soil types, maximum percent soil moisture was recorded in black soil (5.7%), followed by lateritic soil (4.8%) and red soil (4.2%). Maximum soil temperature at 10 cm depth was recorded during May 2005 (46.3^{0}C), followed by June 2005 (44.3^{0}C) and April 2005 (36.4^{0}C). Differences in sub-soil temperatures were non-significant in different soil types. Maximum soil surface temperature was recorded during May 2005 (71.4^{0}C), followed by June 2005 (59.4^{0}C) and April 2005 (46.4^{0}C). Among three soil types, maximum surface temperature was recorded in black soil (61.7^{0}C), followed by lateritic soil (59.0^{0}C) and red soil (56.5^{0}C).

4.3 Isolation of VAM Fungi, Purification and Multiplication:

Six cultures of *Glomus* species and one culture of *Acaulospora*, were purified form trap cultures set for AM fungi from rhizospheric soil of selected plants of Aonla, Ber, Chironji and Lasoda. Characteristics of isolated were as under:

4.3.1 ***Acaulospora* I:** Sporocarp un-known. Spores yellow to light brown under stereo microscope, globose, 108-127 µm in diameter. Remains of sporiferous saccule were seen in some spores. Composite spores wall group 13 µ thick and consisted of four walls in two wall groups (group A & B). Walls group A composed of two layers. Wall 1, yellow (under compound microscope) had ornamentation. Wall 2, an adhering but separable, smooth, hyaline layer. Wall group B composed by wall 3 and wall 4, both hyaline. Spore contents vacuolated. Reaction to meltzer's reagent: outer three spore wall layers yellow, innermost layer quickly belonging deep red on contact. Tentatively identified as *Acaulospora scrobiculata.*

4.3.2 ***Glomus* 1:** Sporocarp present, blackish yellow in reflected light. Chlamydospores formed singly or in clusters in the root, rarely formed outside roots. Chalymydospores predominantly globose (84)-96(125) µ diameter but

frequently subglobose. Composite spores wall 7.2 μ thick, dark brown under stereo microscope spore with 1 or 2, occasionally up to 4 laminated walls. Walls of the spores extending into the hyphal attachment. Subtanding hyphae is single, (7.2) -11.52-(14.5) μ in diameter at the spore base. The hyphal wall at the point subtending the spore is (2.4)-5.16-(12) μ thick.

4.3.3 ***Glomus* 2:** Sporocarp present brownish yellow. Chlamydospores borne singly or in loose clusters in the soil. Globose (36) - 49 (72) μ, light yellow under stereo microscope. Spore wall 3.5 μ thick, consist of single wall layer. Spore lighter in colour than the spore wall. Walls of the spores extending into the hyphal attachment and both are same in color. Hypha at the point of spore attachment 8.64 μ wide with 2.4-4.5 μ thick wall, without septum. Pore usually open 1.92 μ in diameter.

4.3.4 ***Glomus* 3:** Sporocarp present yellow to brown in reflected light. Chlamydospores borne singly or in clusters in the root, rarely formed outside roots, yellow to light brown in under stereo microscope in reflected light, globose to subglobose, 60-124 x 55-120 μ in diameter with single subtending hyphae. Composite spores wall 4.2 μ thick spores with 1 or 2 laminated walls. Subtending hyphae straight or slightly recurved, septate, (4.8-) 8.7 (-12) μ wide, with walls (1.2-) 2.4 (-2.4) μ thick at the base with a septum, pore diameter (2.4-) 3.7 (-4.8) μ thick.

4.3.5 ***Glomus* 4:** Sporocarp turmeric yellow in reflected light under stereo microscope. Chlamydospores borne singly or in clusters in the root, brownish yellow in reflected light under stereo microscope, globose to subglobose, 38-115 x 43-103 μ in diameter with single subtending hyphae. Composite spores wall (3.6-) 5.0 (-7.2) μ thick under stereo microscope spore with 1 or 2, laminated walls. Subtending hyphae straight or slightly recurved (9.6-) 10.6 (-12) μ wide, with walls (2.4-) 3.7 (-5.4) μ thick at the spore base, pore 3 μ wide in diameter.

Table 4.19 Characteristics of VAM species isolated from rhizosphere of Aonla, Ber, Chironji and Lasoda

Characters		VAM species						
		Acaulospora 1	*Glomus* 1	*Glomus* 2	*Glomus* 3	*Glomus* 4	*Glomus* 5	*Glomus* 6
Spore Color		Brown	Dark yellow	Light yellow	Yellow to light brown	Brownish Yellow	Creamish yellow	Silver Shiny
Spore size	Mean (µ)	115x115	96x96	49x49	84x81	76x76	59x56	54.2x54
	Range (µ)	108-127	84-120x86-125	36-72	60-124x55-120	38-115x43-103	36-96x33-76	48-72x48-67
Composite spore wall width (µ)		13	7.2	3.5	4.2	5.0	4	2.4
No. of wall groups		2	1	1	1	1	1	1
Muronym		?A(U_o)B(UM)	?A(L)		?A(L)	?A(L)		
Presence of attachment		-	+	+	+	+	+	+
Presence of hyphal terminus		+	-	-	-	-	-	-
Wall reaction to Meltzer's reagent		+	-	-	-	-	-	-
Spores formation within roots		-	+	-	+	+	+	+
Presence of spores in extrametrical hyphae		-	-	+	-	-	-	+
Presence of sporocarp		-	+	+	+	+	+	+
Sporocarp color		-	Blackish yellow	Light brownish yellow	Yellow to brown	Yellowish (turmeric)	Creamish yellow	Creamish yellow
Surface ornamentation		+	-	-	-	-	-	-

* - Absent + Present

4.3.6 ***Glomus* 5:** Chlamydospore formed in sporocarp and roots. Sporocarp color creemish yellow in reflected light under stereo microscope. Chlamydospore globose to subglobose. Spore diameter average (36-) 59 (-96) x (33-) 56 (-76), spores creamish yellow in reflected light under stereo microscope with 2.5-5 μ thick wall, two wall groups are present and inner wall is dark in color. Subtending hyphae 50 μ long, straight or slightly recorvate, septate, hyline, 5 μ thick at the base of spore.

4.3.7 ***Glomus* 6:** Chlamydospore formed in loose clusters or in sporocarp and rarely in roots. Sporocarp forming outside the root in the month between September to December in pot culture. Sporocarps creamish yellow in reflected light under stereo microscope. Chlamydospore globose, subglobose, silver shiney colored, spore diameter (48-) 54.2 (-72) x (48-) 54(-67) μ , wall upto 2.4 μ thick. Hyphae septate, (4.8-) 7 (-5.6) μ wide at spore base, wall upto 2.8 μ thick. Pore usually opens sometime, closed by a septum, 2.6 μ wide. Color of spore and hypha, walls both are same.

4.4 Screening of VAM Species for Good Plant Growth:

4.4.1 Effect of VAM inoculation on Aonla: Results on effect of inoculation of different VAM species on growth and P uptake of Aonla (*Emblica officinalis* Gaertn.) seedlings are presented in Table 4.20 and Fig. 4.8.

***Shoot length*:** After one month, maximum shoot length was recorded in *Glomus* 6 (20.7 cm), which was significantly superior to control (13.7 cm). Rest of treatments viz., *Glomus* 3 (17.2 cm), *Glomus* 1 (17.0 cm), *Acaulospora* 1 (15.3 cm), *Glomus* 5 (14.0 cm), *Glomus* 4 (13.2 cm) and *Glomus* 2 (11.8 cm) were at par with control. After two months, shoot length was significantly more in *Glomus* 1 (59.8 cm), *Glomus* 3 (57.8 cm) and *Acaulospora* 1 (55.3 cm) than control (45.7 cm). While all other treatments namely, *Glomus* 4 (52.5 cm), *Glomus* 6 (48.5 cm) and *Glomus* 5 (44.5 cm) were at par with control. *Glomus* 2 (36.3 cm) was significantly less than control. After three months,

shoot length was significantly more in *Glomus* 1 (79.0 cm) and *Glomus* 4 (66.3 cm) than control (51.3 cm). While all other treatments namely, *Glomus* 3 (64.8 cm), *Glomus* 5 (60.6 cm), *Acaulospora* 1 (59.3 cm), *Glomus* 2 (55.0 cm) and *Glomus* 6 (52.8 cm) were at par with control. Same trend was observed after four months. Shoot length was significantly more in *Glomus* 1 (82.7 cm) and *Glomus* 4 (74.3 cm) than control. While all other treatments namely, *Glomus* 3 (69.2 cm), *Glomus* 5 (63.3 cm), *Acaulospora* 1 (63.3 cm), *Glomus* 2 (61.0 cm) and *Glomus* 6 (57.3 cm) were at par with control (56.5 cm). After five months, shoot length was significantly more in *Glomus* 1 (85.8 cm) than control. While all other treatments viz., *Glomus* 4 (73.5 cm), *Glomus* 3 (73.2 cm), *Acaulospora* 1 (65.0 cm), *Glomus* 2 (64.2 cm), *Glomus* 5 (63.5 cm) and *Glomus* 6 (60.3 cm) were at par with control (59.5 cm). At harvest, shoot length was significantly more in *Glomus* 1 (88.5 cm) and *Glomus* 4 (77.8 cm). While all other treatments namely, *Glomus* 3 (75.0 cm) *Acaulospora* 1 (66.7 cm), *Glomus* 6 (66.0 cm), *Glomus* 5 (64.3 cm) and *Glomus* 2 (62.3 cm) were at par with control (62.7 cm).

***Collar diameter*:** After one month, maximum collar diameter was recorded in *Glomus* 1 (2.4 mm), followed by *Acaulospora* 1 (2.4 mm), *Glomus* 6 (2.3 mm), *Glomus* 2 (2.3 mm), *Glomus* 4 (2.2 mm), *Glomus* 3 (2.2 mm) and *Glomus* 5 (2.0 mm) which were at par with control (2.4 mm). After two months, same trend was recorded in all treatments, which were at par with control. After three months, significantly superior collar diameter were recorded in *Glomus* 1 (7.0 mm), *Glomus* 3 (6.6 mm) and *Acaulospora* 1 (6.2 mm) than control (4.9 mm). While all other treatments namely *Glomus* 6 (5.7 mm), *Glomus* 5 (5.5 mm), *Glomus* 4 (5.2 mm) and *Glomus* 2 (4.5 mm) were at par with control. Collar diameter after four months was significantly more in *Glomus* 1 (9.5 mm). While all other treatments viz., *Glomus* 2 (8.0 mm), *Glomus* 3 (8.0 mm) *Acaulospora* 1 (8.0 mm), *Glomus* 6 (7.9 mm), *Glomus* 4 (7.6 mm) and *Glomus* 5 (7.0 mm) were at par with control (7.3 mm). After five months, collar diameter was significantly more *Glomus* 1 (10.8 mm.),

while all treatments namely, *Glomus* 3 (9.0 mm), *Acaulospora* 1 (9.0 mm) *Glomus* 2 (8.8 mm), *Glomus* 4 (8.8 mm), *Glomus* 6 (8.7 mm) and *Glomus* 5 (7.5 mm) were at par with control (8.0 mm). At harvest, significantly superior collar diameter was recorded in *Glomus* 1 (11.4 mm). While other treatments namely *Glomus* 3 (9.6 mm), *Acaulospora* 1 (9.6 mm), *Glomus* 4 (9.5 mm), *Glomus* 2 (9.4 mm), *Glomus* 6 (9.4 mm) and *Glomus* 5 (8.1 mm) were at par with control (8.5 mm).

Fresh weight: At harvest, maximum fresh weight of the shoot was recorded in *Glomus* 1 (36.88 g), followed by *Glomus* 6 (31.96 g), *Glomus* 4 (30.93 g) and *Glomus* 3 (27.80 g) which were significantly more than control (19.02 g). *Acaulospora* 1(24.58 g), *Glomus* 5 (20.62 g) and *Glomus* 2 (17.30 cm) were at par with control. Fresh weight of root was recorded in *Glomus* 1 (86.08 g), *Glomus* 6 (78.14 g), *Acaulospora* 1 (76.80 g), *Glomus* 3 (74.11 g), *Glomus* 4 (69.59 g) and *Glomus* 5 (67.51 g) were at par with control (70.78 g). *Glomus* 2 (48.33 g) was the poorest and significantly less than control.

Dry weight: At harvest maximum dry weight of the shoot was recorded in *Glomus* 1 (17.58 g), followed by *Glomus* 4 (15.08 g), *Acaulospora* 1 (14.37 g), *Glomus* 3 (13.34 g) and *Glomus* 6 (12.67 g) which were significantly more than control (9.56 g). While *Glomus* 5 (9.63 g) was at par with control. *Glomus* 2 (6.43 g) was significantly less than control. At harvest, maximum dry weight of the root was recorded in *Glomus* 1 (29.55 g), followed by *Glomus* 6 (26.53 g), *Acaulospora* 1 (26.43 g) and *Glomus* 3 (25.23 g), which were significantly more than control (20.53 g). *Glomus* 4 (23.69 g) and *Glomus* 5 (22.36 g) were at par with control. *Glomus* 2 (15.43 g) was less than control.

Phosphorus: Maximum phosphorus uptake per plant was recorded in *Glomus* 3 (97.197 mg), followed by *Acaulospora* 1 (72.383 mg) and *Glomus* 6 (57.977 mg) which were significantly superior to control. *Glomus* 4 (55.000 mg), *Glomus* 1 (51.380 mg) and *Glomus* 5 (40.657 mg) were at par with control (47.423 mg). *Glomus* 2 (28.277 mg) was significantly less than control.

Table 4.20 Effect of inoculation of different VAM species on growth and P uptake of Aonla (*Emblica officinalis* Gaertn.) seedlings

VAM cultures	Shoot length after (cm)						Collar diameter after (mm)						Fresh weight (g)		Dry weight (g)		P uptake per plant (mg)
	One month	Two month	Three month	Four month	Five month	At harvest	One month	Two month	Three month	Four month	Five month	At harvest	Shoot	Root	Shoot	Root	
Acaulospora 1	15.3	55.3	59.3	63.3	65.0	66.7	2.4	4.6	6.2	8.0	9.0	9.6	24.58	76.80	14.37	26.43	72.383
Glomus 1	17.0	59.8	79.0	82.7	85.8	88.5	2.4	5.3	7.0	9.5	10.8	11.4	36.88	86.08	17.58	29.55	51.380
Glomus 2	11.8	36.3	55.0	61.0	64.2	62.3	2.3	4.0	4.5	8.0	8.8	9.4	17.30	48.33	6.43	15.43	28.277
Glomus 3	17.2	57.8	64.8	69.2	73.2	75.0	2.2	5.1	6.6	8.0	9.0	9.6	27.80	74.11	13.34	25.23	97.197
Glomus 4	13.2	52.5	66.3	74.3	73.5	77.8	2.2	4.0	5.2	7.6	8.8	9.5	30.93	69.59	15.08	23.69	55.000
Glomus 5	14.0	44.5	60.6	63.3	63.5	64.3	2.0	4.2	5.5	7.0	7.5	8.1	20.62	67.51	9.63	22.36	40.657
Glomus 6	20.7	48.5	52.8	57.3	60.3	66.0	2.3	5.2	5.7	7.9	8.7	9.4	31.96	78.14	12.67	26.53	57.977
Control	13.7	45.7	51.3	56.5	59.5	62.7	2.4	4.5	4.9	7.3	8.0	8.5	19.02	70.78	9.56	20.53	47.423
S. Em.±	1.7	2.6	5.0	4.9	5.0	5.0	0.2	0.3	0.3	0.5	1.7	0.7	2.0	3.7	0.8	1.5	3.296
C.D. (0.05%)	4.9	7.9	15.0	14.6	15.1	14.9	0.5	0.9	0.8	1.6	4.9	2.0	6.0	11.1	2.5	4.4	9.880

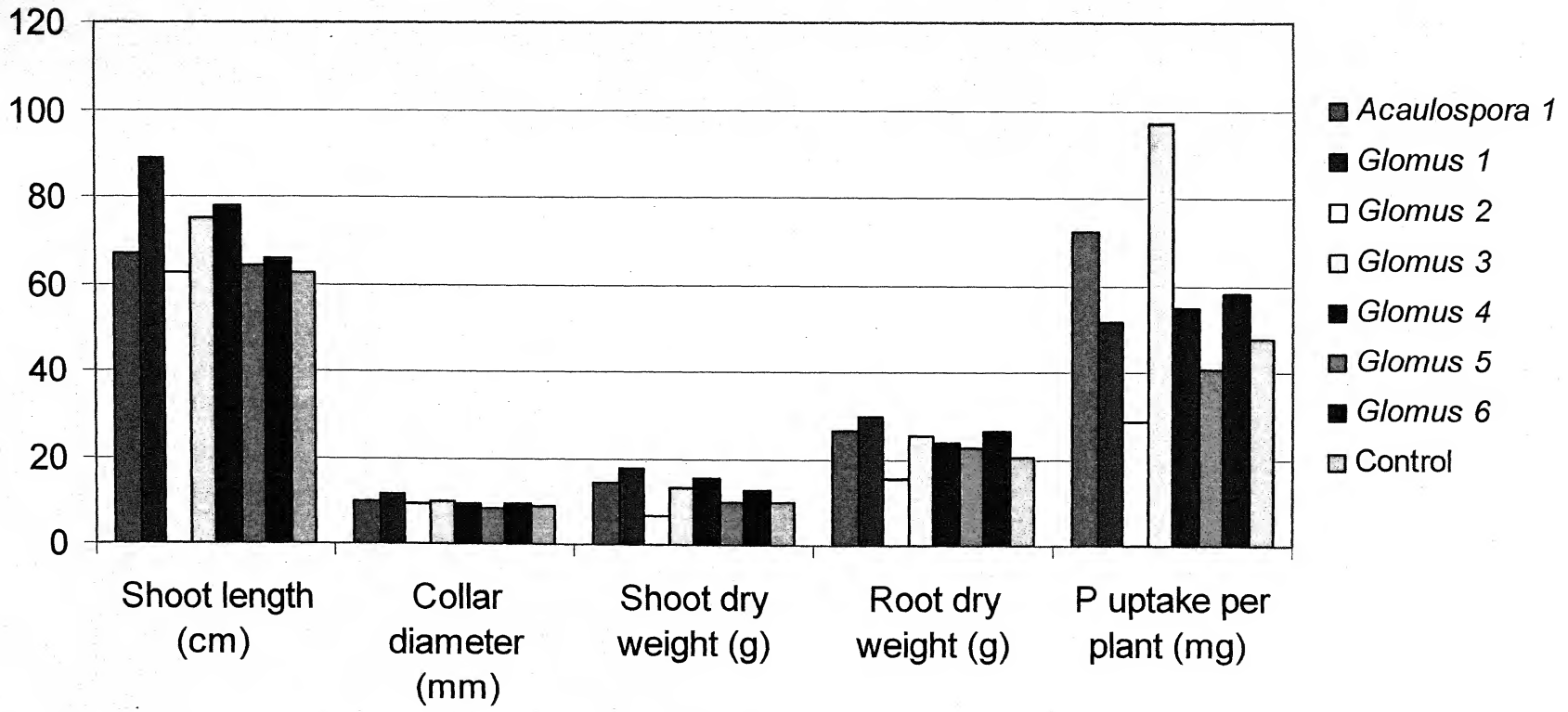


Fig. 4.8 Effect of VAM inoculations on growth and P uptake of Aonla (*Emblica officinalis* Gaertn.) seedlings

In short, *Glomus* 1 and *Glomus* 4 significantly increased shoot length of Aonla, *Glomus* 1 significantly increased collar diameter, *Glomus* 1, *Glomus* 6, *Glomus* 4 and *Glomus* 3 significantly increased fresh shoot weight, *Glomus* 1, *Glomus* 4, *Acaulospora* 1, *Glomus* 3 and *Glomus* 6 significantly increased dry shoot weight and *Glomus* 1, *Glomus* 6, *Acaulospora* 1, and *Glomus* 3 significantly increased dry root weight. *Glomus* 3, *Acaulospora* 1 and *Glomus* 6 significantly increased P uptake per plant. Rests of treatments were found ineffective.

4.4.2 Effect of VAM inoculation on Ber: Results on effect of inoculation of different VAM species on growth and P uptake of Ber (*Zizyphus mauritiana* Lamk.) seedlings are presented in Table 4.21 and Fig. 4.9.

Shoot length: After one month, maximum shoot length was recorded in *Glomus* 4 (15.3 cm), which was significantly superior to control (11.5 cm). *Glomus* 3 (14.5 cm), *Acaulospora* 1 (14.5 cm), *Glomus* 1 (12.8 cm), *Glomus* 5 (12.3 cm), *Glomus* 2 (11.7 cm) and *Glomus* 6 (11.3 cm) were at par with control. After two months, shoot length was significantly more in *Glomus* 3 (49.8 cm) and *Glomus* 4 (47.8 mm) than control (36.8 cm). *Glomus* 1 (43.7 cm), *Glomus* 6 (42.3 cm), *Acaulospora* 1 (35 cm) and *Glomus* 5 (33.8 cm) were at par with control. *Glomus* 2 (27.3 cm) was significantly less than control. After three months, shoot length in *Glomus* 3 (68.0 cm), *Glomus* 1 (65.7 cm), *Glomus* 4 (63.0 cm), *Glomus* 6 (59.7 cm) and *Acaulospora* 1 (57.5 cm) were at par with control (61.0 cm). *Glomus* 5 (51.0 cm) and *Glomus* 2 (42.0 cm) were significantly less than control. After four months, maximum shoot length was recorded in *Glomus* 1 (91.2 cm), which was significantly more than control (77.5 cm). *Glomus* 3 (84.8 cm), *Glomus* 4 (80.0 cm), *Glomus* 6 (79.3 cm), *Glomus* 5 (75.2 cm) and *Acaulospora* 1 (67.5 cm) were at par with control. *Glomus* 2 (55.7 cm) was significantly less than control. After five months, G*lomus* 1 (97.2 cm), *Glomus* 3 (91.7 cm), *Glomus* 6 (87.3 cm), *Glomus* 4 (85.8 cm) and *Glomus* 5 (79.0 cm) were at par with control (89.3 cm). *Acaulospora* 1 (74.8 cm) and *Glomus* 2 (64.2 cm) were significantly less

than control. At harvest, *Glomus* 1 (104.3), *Glomus* 3 (94.2), *Glomus* 6 (92.3), *Glomus* 4 (89.0) and *Glomus* 5 (82.3) were at par with control (92.8). *Acaulospora* 1 (79.0 cm) and *Glomus* 2 (66.5 cm) were significantly less than control.

Collar diameter: After one month, maximum collar diameter was recorded in *Glomus* 3 (3.1 mm), which was significantly more than control (2.5 mm). *Glomus* 6 (2.9 mm), *Glomus* 4 (2.7 mm), *Glomus* 2 (2.7 mm), *Glomus* 1 (2.5 mm), *Glomus* 5 (2.4 mm) and *Acaulospora* 1 (2.4 mm) were at par with control. After two months, collar diameter was significantly more in *Glomus* 4 (4.7 mm), *Glomus* 1 (4.2 mm), *Glomus* 6 (4.1 mm) and *Glomus* 5 (4.1 mm) than control (3.5 mm). *Glomus* 3 (4.0 mm) *Acaulospora* 1 (3.6 mm) and *Glomus* 2 (3.1 mm) were at par with control. After three months, collar diameter was significantly more in *Glomus* 1 (7.8 mm) and *Glomus* 3 (7.2 mm) than control (5.7 mm). *Glomus* 4 (6.7 mm), *Glomus* 6 (6.3 mm), *Glomus* 5 (6.1 mm), *Acaulospora* 1 (5.8 mm) and *Glomus* 2 (5.2 mm) were at par with control. After four months, maximum collar diameter was recorded in *Glomus* 1 (8.3 mm). *Glomus* 3 (7.8 mm), *Glomus* 4 (7.6 mm), *Glomus* 5 (6.9 mm) and *Glomus* 6 (6.7 mm) were at par with control (8.1 mm). *Glomus* 2 (6.5 mm) and *Acaulospora* 1 (6.4 mm) were significantly less than control. After five months, maximum collar diameter was recorded in *Glomus* 1 (8.9 mm). *Glomus* 3 (8.7 mm), *Glomus* 4 (8.0 mm), *Glomus* 5 (7.5 mm), *Glomus* 6 (7.3 mm) and *Acaulospora* 1 (7.0 mm) were at par with control (8.5 mm). *Glomus* 2 (6.0 mm) was significantly less than control. At harvest, all treatments viz., *Glomus* 1 (9.8 mm), *Glomus* 3 (9.4 mm), *Glomus* 6 (9.3 mm), *Glomus* 4 (8.5 mm), *Glomus* 5 (7.9 mm), *Acaulospora* 1 (7.4 mm) and *Glomus* 2 (7.3 mm) were at par with control (9.0 mm).

Fresh weight: At harvest, significantly superior fresh weight of the shoot was recorded in *Glomus* 1 (48.07 g) and *Glomus* 6 (38.78 g). *Glomus* 3 (35.86 g), *Glomus* 4 (35.18 g) and *Glomus* 5 (25.93 g) were at par with control (31.38 g). *Acaulospora* 1 (24.76 g) and *Glomus* 2 (17.62 cm) were significantly less than

Table 4.21 Effect of inoculation of different VAM species on growth and P uptake of Ber (*Zizyphus mauritiana* Lamk.) seedlings

VAM cultures	Shoot length after (cm)						Collar diameter after (mm)						Fresh weight (g)		Dry weight (g)		P uptake per plant (mg)
	One month	Two month	Three month	Four month	Five month	At harvest	One month	Two month	Three month	Four month	Five month	At harvest	Shoot	Root	Shoot	Root	
Acaulospora 1	11.5	35.0	57.5	67.5	74.8	79.0	2.4	3.6	5.8	6.4	7.0	7.4	24.76	32.82	11.68	14.58	51.930
Glomus 1	11.5	43.7	65.7	91.2	97.2	104.3	2.5	4.2	7.8	8.3	8.9	9.8	48.07	48.59	22.73	20.58	68.507
Glomus 2	11.5	27.3	42.0	55.7	64.2	66.5	2.7	3.1	5.2	6.5	6.4	7.3	17.62	17.72	8.84	8.26	25.170
Glomus 3	13.0	49.8	68.0	84.8	91.7	94.2	3.1	4.0	7.2	7.8	8.7	9.4	35.86	62.42	17.46	26.75	75.897
Glomus 4	15.5	47.8	63.0	80.0	85.8	89.0	2.7	4.7	6.7	7.6	8.0	8.5	35.18	59.43	17.14	22.37	48.223
Glomus 5	11.0	33.8	51.0	75.2	79.0	82.3	2.4	4.1	6.1	6.9	7.5	7.9	25.93	41.44	12.62	16.39	25.410
Glomus 6	13.0	42.3	59.7	79.3	87.3	92.3	2.9	4.1	6.3	6.7	7.3	9.3	38.78	57.90	18.38	22.78	64.537
Control	10.5	36.8	61.0	77.5	89.3	92.8	2.5	3.5	5.7	8.1	8.5	9.0	31.38	30.45	17.15	14.03	40.01
S. Em.±	1.14	3.13	3.14	4.29	4.29	4.34	0.14	0.17	0.40	0.46	0.54	0.64	2.05	5.21	1.16	2.10	4.067
C.D. (0.05%)	3.43	9.38	9.40	12.85	12.85	13.02	0.43	0.52	1.20	1.38	1.62	1.94	6.15	15.63	3.48	6.30	12.192

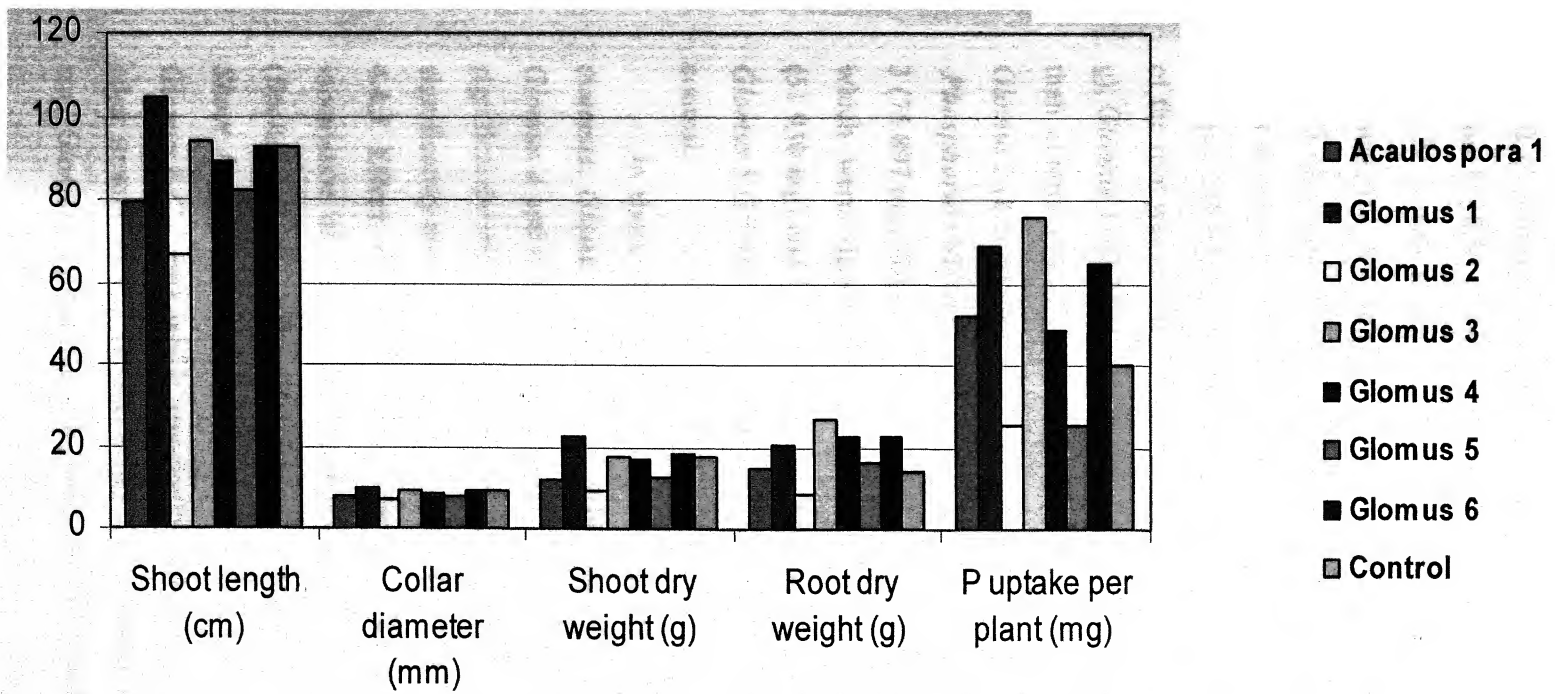


Fig. 4.9 Effect of VAM inoculations on growth and P uptake of Ber (*Zizyphus mauritiana* Lamk.) seedlings

control. Significantly superior fresh weight of root was recorded in *Glomus* 3 (62.42 g) followed by, *Glomus* 4 (59.43 g) and *Glomus* 6 (57.90 g). While *Glomus* 1 (48.59 g), *Glomus* 5 (41.44 g), *Acaulospora* 1 (32.82 g) and *Glomus* 2 (17.72 g) were at par with control (30.46).

Dry weight: Dry weight of the shoot was significantly more in *Glomus* 1 (22.73 g). *Glomus* 6 (18.38 g), *Glomus* 3 (17.46 g), *Glomus* 4 (17.14 g) were at par with control (17.150). *Glomus* 5 (12.62 g), *Acaulospora* 1 (11.68 g) and *Glomus* 2 (8.84 g) were significantly less than control. Maximum dry weight of the root was recorded in *Glomus* 3 (26.75 g), followed by *Glomus* 6 (22.78 g), *Glomus* 4 (22.37 g) and *Glomus* 1 (20.58 g), which were significantly more than control (14.03 g). *Glomus* 5 (16.39 g), *Acaulospora* 1 (14.59 g) and *Glomus* 2 (8.26 g) were at par with control.

Phosphorus: Maximum phosphorus uptake per plant was recorded in *Glomus* 3 (75.897 mg), followed by *Glomus* 1 (68.507 mg) and *Glomus* 6 (64.537 mg), which were significantly more than control (40.01 mg). *Acaulospora* 1 (51.930 mg) and *Glomus* 4 (48.223 mg) were at par with control (40.01 mg). *Glomus* 5 (25.410 mg) and *Glomus* 2 (25.170 mg) were significantly less than control.

In short, none of tested VAM fungi increased shoot length and collar diameter, *Glomus* 1 and *Glomus* 5 increased fresh shoot weight, *Glomus* 3, *Glomus 4* and *Glomus* 2 significantly increased dry shoot weight, *Glomus* 3 significantly increased dry root weight and phosphorus uptake per plant was significantly more in *Glomus* 3, *Glomus* 1 and *Glomus* 6.

4.4.3 Effect of VAM inoculation on Chironji: Results on effect of inoculation of different VAM species on growth and P uptake of Chironji (*Buchanania lanzan* Spr.) seedlings are presented in Table 4.22 and Fig. 4.10.

Shoot length: After one month, maximum shoot length was recorded in *Glomus* 6 (7.2 cm), which was significantly superior to control (5.5 cm). All other treatments viz., *Glomus* 4 (6.3 cm), *Glomus* 1 (6.2 cm), *Glomus* 5 (5.7 cm), *Glomus* 2 (5.3 cm) and *Acaulospora* 1 (5.0 cm) were at par with control.

Glomus 3 (3.3 cm) was significantly less than control. After two months, shoot length was significantly more in *Glomus* 4 (9.8 cm) and *Glomus* 6 (9.7 cm) than control (6.0 cm). *Glomus* 1 (7.2 cm), *Glomus* 5 (7.0 cm), *Acaulospora* 1(6.8 cm), *Glomus* 2 (6.5 cm) and *Glomus* 3 (6.2 cm) were at par with control. After three months, shoot length was significantly more in *Glomus* 6 (12.5 cm), *Glomus* 4 (12.5 cm), *Glomus* 1 (12.0 cm) and *Glomus* 3 (10.5 cm) than control (7.0 cm). *Glomus* 5 (8.2 cm), *Acaulospora* 1(8.0 cm) and *Glomus* 2 (7.0 cm) were at par with control. After four months, shoot length, was significantly more in *Glomus* 6 (17.8 cm) and *Glomus* 4 (17.2 cm) than control (8.5 cm). All other treatments viz., *Glomus* 1 (14.67 cm), *Glomus* 3 (13.57 cm), *Acaulospora* 1 (10.83 cm), *Glomus* 5 (10.67 cm) and *Glomus* 2 (7.5 cm) were at par with control. After five months, shoot length was significantly more in *Glomus* 4 (22.7 cm) and *Glomus* 6 (19.7 cm) than control (10.3 cm). *Glomus* 1 (17.3 cm), *Glomus* 3 (15.7 cm), *Acaulospora* 1 (12.0 cm), *Glomus* 5 (11.3 cm) and *Glomus* 2 (7.7 cm) were at par with control. At harvest, shoot length was significantly more in *Glomus* 4 (23.2 cm), *Glomus* 6 (19.8 cm), *Glomus* 1 (18.5 cm), *Glomus* 3 (16.7 cm) and *Glomus* 5 (13.5 cm) than control (10.3 cm). *Acaulospora* 1 (13.0 cm) and *Glomus* 2 (8.8 cm) were at par with control.

Collar diameter: After one month, collar diameter in *Glomus* 3 (4.0 mm) was significantly more than control (2.8 mm). *Acaulospora* 1 (3.1 mm), *Glomus* 4 (3.1 mm), *Glomus* 2 (3.0 mm), *Glomus* 1 (2.7 mm), *Glomus* 5 (2.5 mm) and *Glomus* 6 (2.5 mm) were at par with control. After two months, all treatments namely, *Glomus* 4 (3.8 mm), *Acaulospora* 1 (3.5 mm), *Glomus* 6 (3.4 mm), *Glomus* 5 (3.1 mm), *Glomus* 1 (3.1 mm), *Glomus* 2 (3.0 mm) and *Glomus* 3 (3.0 mm) were at par with control (3.5 mm). After three months, collar diameter was significantly more in *Glomus* 4 (5.1 mm) *Glomus* 1 (4.9 mm), *Glomus* 6 (4.3 mm), *Acaulospora* 1 (4.3 mm) and *Glomus* 3 (4.2 mm) than control (3.0 mm). While other treatments viz., *Glomus* 5 (3.8 mm) and *Glomus* 2 (3.7 mm) were at par with control. After four months, collar diameter was

significantly more in *Glomus* 4 (6.7 mm), *Glomus* 1 (5.9 mm), *Glomus* 6 (5.2 mm), *Acaulospora* 1 (4.8 mm) and *Glomus* 3 (4.6 mm) than control (3.3 mm). *Glomus* 5 (4.1 mm) and *Glomus* 2 (4.0 mm) were at par with control. After five months, collar diameter was significantly more in *Glomus* 4 (7.1 mm), *Glomus* 6 (6.4 mm), *Glomus* 1 (6.2 mm), *Acaulospora* 1 (5.3 mm), *Glomus* 3 (4.9 mm) and *Glomus* 5 (4.8 mm) than control (3.5 mm). *Glomus* 2 (4.3 mm) was at par with control. At harvest, collar diameter was significantly more in *Glomus* 4 (7.5 mm), *Glomus* 6 (7.0 mm), *Glomus* 1 (6.4 mm), *Acaulospora* 1 (5.5 mm), *Glomus* 5 (5.3 mm) and *Glomus* 3 (5.2 mm) than control (3.9 mm). *Glomus* 2 (4.4 mm) was at par with control.

Fresh weight: At harvest, fresh weight of the shoot was significantly more in *Glomus* 6 (20.95 g), *Glomus* 4 (20.56 g), *Glomus* 1 (14.69 g) and *Glomus* 3 (9.98 g) than control (4.6 g). *Acaulospora* 1 (8.27 g), *Glomus* 5 (6.71 g) and *Glomus* 2 (4.28 cm) were at par with control. Fresh weight of the root was significantly more in *Glomus* 4 (23.78 g), *Glomus* 6 (20.97 g), *Glomus* 1 (17.83 g) and *Glomus* 3 (14.99 g) than control (6.67 g). *Acaulospora* 1 (11.19 g), *Glomus* 2 (10.22 g) and *Glomus* 5 (8.66 g) were at par with control.

Dry weight: At harvest, dry weight of the shoot was significantly more in *Glomus* 4 (7.74 g), *Glomus* 6 (7.10 g), *Glomus* 1 (4.98 g) and *Glomus* 3 (4.05 g) than control (1.9 g). *Acaulospora* 1 (2.88 g), *Glomus* 5 (2.80 g) and *Glomus* 2 (1.84 g) were at par with control. Dry weight of the root was significantly more in *Glomus* 4 (8.64 g), *Glomus* 6 (7.06 g), *Glomus* 3 (4.76 g) and *Glomus* 1 (4.61 g) than control (2.4 g). *Acaulospora* 1 (3.56 g), *Glomus* 2 (3.56) and *Glomus* 5 (3.10 g), were at par with control.

Phosphorus: Phosphorus uptake per plant was significantly more in *Glomus* 6 (22.487 mg) *Glomus* 1 (15.733 mg), *Acaulospora* 1 (15.570 mg) and *Glomus* 4 (12.857 mg) than control (7.857 mg). *Glomus* 3 (9.437 mg), *Glomus* 2 (6.683 mg) and *Glomus* 5 (6.073 mg) were at par with control.

In general, among tested VAM species *Glomus* 4 was found more effective in increasing biomass of Chironji in terms of shoot length, collar

Table 4.22 Effect of inoculation of different VAM species on growth and P uptake of Chironjii (*Buchanania lanzan* Spr.) seedlings

VAM cultures	Shoot length after (cm)						Collar diameter after (mm)						Fresh weight (g)		Dry weight (g)		P uptake per plant (mg)
	One month	Two month	Three month	Four month	Five month	At harvest	One month	Two month	Three month	Four month	Five month	At harvest	Shoot	Root	Shoot	Root	
Acaulospora 1	5.0	6.8	8.0	10.8	12.0	13.0	3.1	3.5	4.3	4.8	5.3	5.5	8.27	11.19	2.88	3.56	15.570
Glomus 1	6.2	7.2	12.0	14.7	17.3	18.5	2.7	3.1	4.9	5.9	6.2	6.4	14.69	17.83	4.98	4.61	15.733
Glomus 2	5.3	6.5	7.0	7.5	7.7	8.8	3.0	3.0	3.7	4.0	4.3	4.4	4.28	10.22	1.84	3.56	6.683
Glomus 3	3.3	6.2	10.5	13.6	15.7	16.7	4.0	3.0	4.2	4.6	4.9	5.2	10.00	14.99	4.05	4.76	9.437
Glomus 4	6.3	9.8	12.5	17.2	22.7	23.2	3.1	3.8	5.1	6.7	7.1	7.5	20.56	23.78	7.74	8.64	12.857
Glomus 5	5.7	7.0	8.2	10.7	11.3	13.5	2.5	3.1	3.8	4.1	4.8	5.3	6.71	8.66	2.80	3.10	6.073
Glomus 6	7.2	9.7	12.5	17.8	19.7	19.8	2.5	3.4	4.3	5.2	6.4	7.0	21.00	20.97	7.10	7.06	22.487
Control	5.5	6.0	7.0	8.5	10.3	10.3	2.8	3.5	3.0	3.3	3.5	3.9	4.61	6.68	1.91	2.42	7.857
S. Em.±	0.47	0.79	1.06	2.26	2.78	1.04	0.27	0.26	0.42	0.34	0.31	1.24	3.82	2.44	0.74	0.56	1.343
C.D. (0.05%)	1.4	2.4	3.2	6.8	8.4	3.1	0.8	0.8	1.2	1.0	0.9	1.2	3.8	7.3	1.5	1.7	4.026

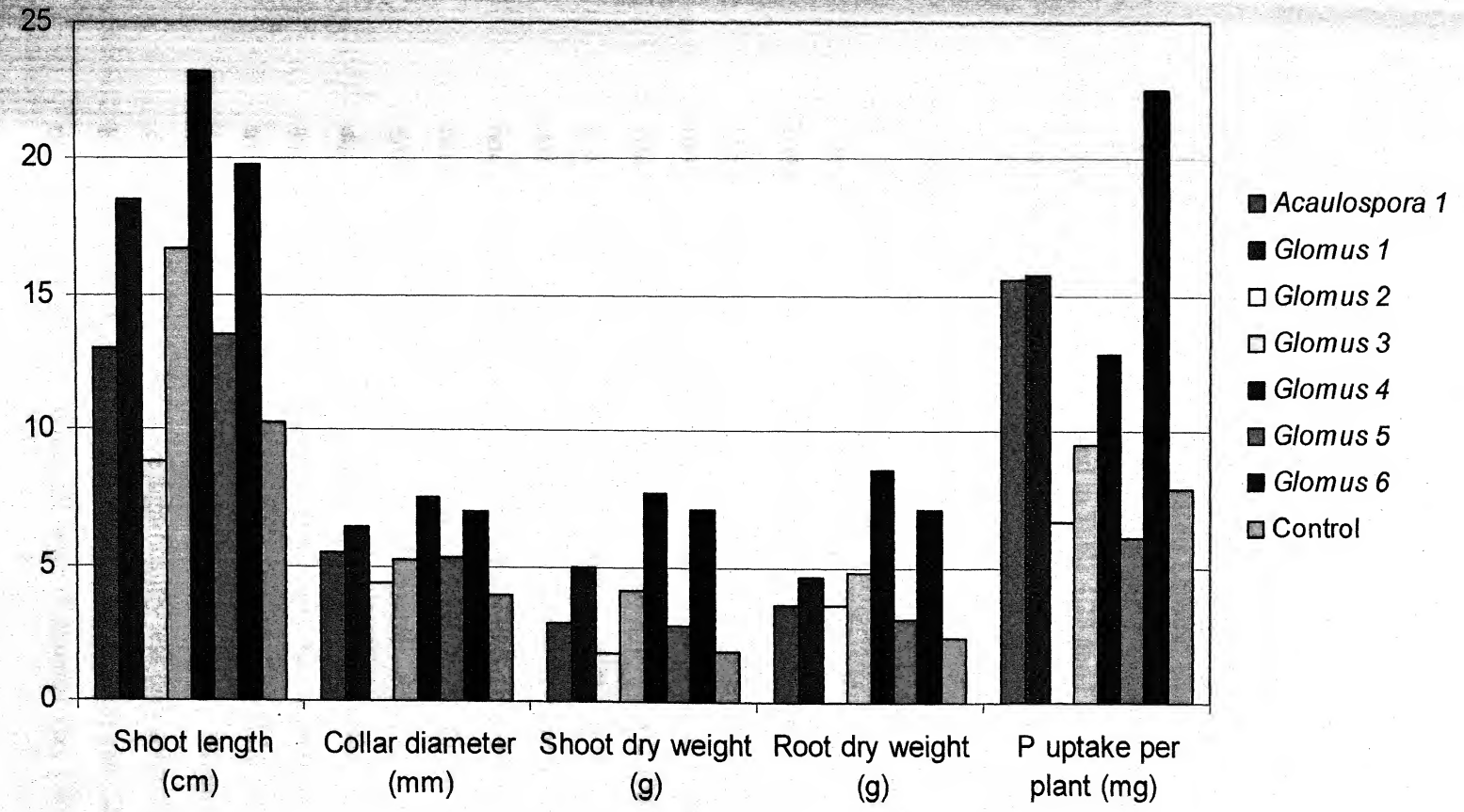


Fig. 4.10 Effect of VAM inoculation on growth and P uptake of Chironji (*Buchanania lanzan* Spr.) seedlings

diameter, fresh and dry weight of shoot and root, *Glomus* 6, *Glomus* 1 and *Glomus* 3 also increased the shoot length, fresh and dry biomass of the tree species. *Acaulospora* 1 and *Glomus* 5 significantly increased collar diameter but these treatments were at par with control with respect to other tested parameters. *Glomus* 2 decreased the growth of Chironji, however the differences were not significant.

4.4.4 Effect of VAM inoculation on Lasoda: Results on effect of inoculation of different VAM species on growth and P uptake of Lasoda (*Cordia myxa* Roxb.) seedlings are presented in Table 4.23 and Fig. 4.11.

Shoot length: After one month, shoot length in *Glomus* 6 (11.7 cm), *Glomus* 5 (10.7 cm), *Glomus* 4 (10.7 cm), *Glomus* 2 (10.2 cm), *Glomus* 3 (10.2 cm), *Acaulospora* 1 (10.0 cm) and *Glomus* 1 (9.2 cm) was at par with control (10.3 cm). After two months, shoot length was significantly more in *Glomus* 6 (30.0 cm) and *Glomus* 4 (29.3 cm) than control (25.2 cm). While all other treatments namely, *Glomus* 1 (27.3 cm), *Acaulospora* 1 (26.3 cm), *Glomus* 5 (26.0 cm), *Glomus* 3 (25.8 cm) and *Glomus* 2 (24.0 cm) were at par with control. After three months, shoot length in *Glomus* 4 (37.0 cm), *Glomus* 5 (36.8 cm), *Glomus* 1 (34.5 cm), *Glomus* 6 (33.7 cm), *Glomus* 2 (33.0 cm), *Glomus* 3 (33.0 cm) and *Acaulospora* 1 (29.5 cm) were at par with control (33.3 cm). After four months, shoot length was significantly more in *Glomus* 4 (47.7 cm) and *Glomus* 6 (47.0 cm) than control (40.0 cm). While other treatments namely, *Glomus* 5 (45.2 cm), *Glomus* 1 (40.7 cm), *Glomus* 3 (38.0 cm) and *Glomus* 2 (37.0 cm) were at par with control. *Acaulospora* 1 (30.7 cm) was significantly less than control. After five months, shoot length was significantly more in *Glomus* 4 (59.0 cm) than control (47.3). While other treatments namely, *Glomus* 5 (57.0 cm), *Glomus* 6 (57.8 cm), *Glomus* 1 (49.0 cm) *Glomus* 2 (43.3 cm) were at par with control. *Glomus* 3 (36.8 cm) and *Acaulospora* 1 (32.0 cm) were significantly less than control. At harvest, shoot length was significantly more in *Glomus* 4 (60.2 cm) and *Glomus* 5 (57.8 cm) than control (47.3 cm). While all other treatments viz., *Glomus* 1 (53.7 cm),

Glomus 6 (51.9 cm), *Glomus* 2 (45.5 cm) and *Glomus* 3 (38.5 cm) were at par with control. *Acaulospora* 1 (34.8 cm) was significantly less than control.

Collar diameter: After one month, collar diameter in *Glomus* 2 (4.6 mm), *Glomus* 5 (4.3 mm), *Glomus* 6 (4.3 mm), *Glomus* 4 (4.1 mm), *Acaulospora* 1 (4.1mm), *Glomus* 3 (4.0 mm) and *Glomus* 1 (3.6 mm) was at par with control (3.7 mm). After two months, *Glomus* 4 (8.2 mm), *Glomus* 1 (8.0 mm), *Glomus* 6 (7.8 mm), *Acaulospora* 1 (7.6 mm), *Glomus* 5 (7.5 mm) and *Glomus* 2 (7.2 mm) were at par with control. *Glomus* 3 (6.8 mm) was significantly less than control. After three months, collar diameter was significantly more in *Glomus* 6 (14.2 mm) and *Glomus* 4 (12.4 mm) than control (11.0 mm). *Glomus* 5 (11.8 mm), *Glomus* 2 (11.7 mm), *Glomus* 3 (11.6 mm), *Acaulospora* 1 (10.6 mm) and *Glomus* 1 (10.5 mm) were at par with control. After four months, collar diameter was significantly more in *Glomus* 6 (17.0 mm), *Glomus* 3 (15.2 mm), *Glomus* 2 (14.8 mm) and *Glomus* 4 (14.3 mm) than control (12.0 mm). While other treatments namely, *Glomus* 5 (14.0 mm), *Glomus* 1 (13.8 mm), and *Acaulospora* 1 (12.6 mm) were at par with control. After five months, collar diameter was significantly more in *Glomus* 6 (17.5 mm) and *Glomus* 5 (16.9 mm) than control (14.9 mm). While other treatments viz., *Glomus* 2 (16.4 mm), *Glomus* 4 (16.3 mm), *Glomus* 3 (16.2 mm), *Acaulospora* 1 (16.0 mm) and *Glomus* 1 (15.5 mm) were at par with control. At harvest, collar diameter in all treatments viz., *Glomus* 2 (18.8 mm), *Glomus* 6 (18.3 mm), *Glomus* 3 (18.1 mm), *Glomus* 4 (17.7 mm), *Glomus* 1 (17.5 mm), *Glomus* 5 (17.5 mm) and *Acaulospora* 1 (17.5 mm) was at par with control (7.3 mm).

Fresh weight: At harvest, fresh weight of the shoot was significantly more in *Glomus* 4 (64.35 g), *Glomus* 5 (62.79 g), *Glomus* 1 (58.60 g) than control (50.5 cm). *Glomus* 6 (52.66 g) and *Glomus* 2 (50.37 cm) were at par with control. *Glomus* 3 (43.60 cm) and *Acaulospora* 1 (38.38 g) were significantly less than control. Fresh weight of root was significantly more in *Glomus* 2 (106.06 g) and *Glomus* 4 (100.09 g) than control (81.12 g). While other

Table 4.23 Effect of inoculation of different VAM species on growth and P uptake of Lasoda (*Cordia myxa* Roxb.) seedlings

VAM cultures	Shoot length (cm) after						Collar diameter (mm) after						Fresh weight (g)		Dry weight (g)		P uptake per plant (mg)
	One month	Two month	Three month	Four month	Five month	At harvest	One month	Two month	Three month	Four month	Five month	At harvest	Shoot	Root	Shoot	Root	
Acaulospora 1	10.0	26.3	29.5	30.7	32.0	34.8	4.1	7.6	10.6	12.6	16.0	17.5	38.38	80.88	12.23	26.62	80.557
Glomus 1	9.2	27.3	34.5	40.7	49.0	53.7	3.6	8.0	10.5	13.8	15.5	17.5	58.60	96.34	21.10	33.40	110.767
Glomus 2	10.2	24.0	33.0	37.0	43.3	45.5	4.6	7.2	11.7	14.8	16.4	18.8	50.37	106.06	19.60	34.99	86.423
Glomus 3	10.2	25.8	33.0	38.0	36.8	38.5	4.0	6.8	11.6	15.2	16.2	18.1	43.60	92.92	14.83	34.41	84.143
Glomus 4	10.7	29.3	37.0	47.7	59.0	60.2	4.1	8.2	12.4	14.3	16.3	17.7	64.35	100.09	23.82	33.81	80.703
Glomus 5	9.9	26.0	36.8	45.2	57.0	57.8	4.3	7.5	11.8	14.0	16.9	17.5	62.79	93.52	22.75	31.34	82.943
Glomus 6	11.7	30.0	33.7	47.0	51.8	51.9	4.3	7.8	14.2	17.0	17.5	18.3	52.66	85.87	20.25	29.08	78.137
Control	10.3	25.2	33.3	40.0	47.3	47.3	3.9	8.5	11.0	12.0	14.9	17.1	50.50	81.12	19.61	27.62	56.043
S. Em.±	0.88	1.23	1.45	2.1	3.46	3.44	0.31	0.45	0.75	0.69	0.55	0.72	9.6	5.51	1.36	1.36	6.544
C.D. (0.05%)	2.64	3.68	4.31	6.29	10.38	10.32	0.94	1.35	2.24	2.1	1.66	2.16	3.20	16.52	4.09	4.1	19.617

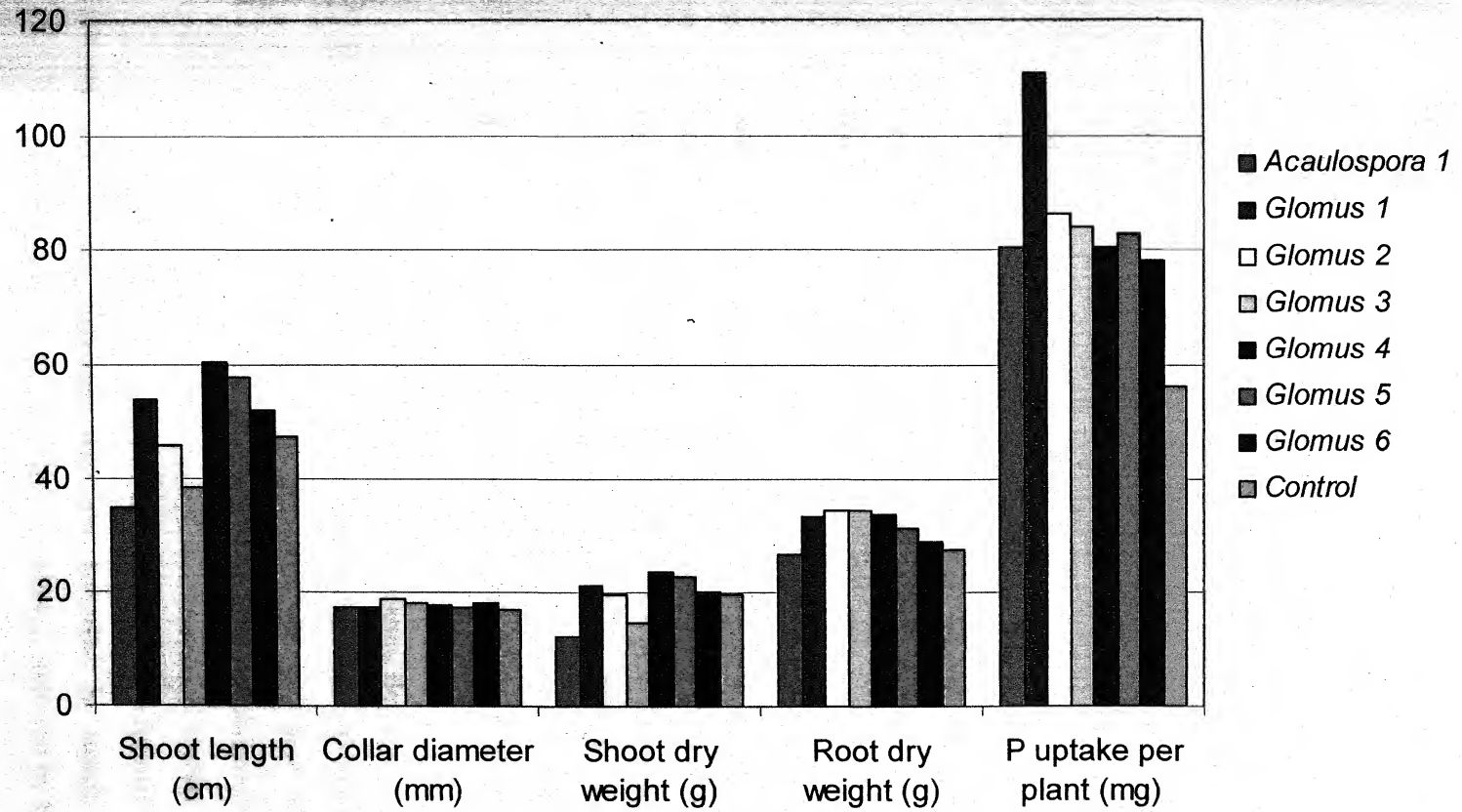


Fig. 4.11 Effect of VAM inoculation on growth and P uptake of Lasoda (*Cordia myxa* Roxb.) seedlings

treatments viz., *Glomus* 1 (96.34 g), *Glomus* 3 (92.92 g), *Glomus* 5 (93.52 g), *Glomus* 6 (85.87 g) and *Acaulospora* 1 (80.88 g) were at par with control.

Dry weight: At harvest, no significant difference was recorded in dry weight of the shoot. *Glomus* 4 (23.82 g), *Glomus* 5 (22.75 g), *Glomus* 1 (21.10 g), *Glomus* 6 (20.25 g) and *Glomus* 2 (19.60 g) were at par with control (19.61). *Glomus* 3 (14.83 g) and *Acaulospora* 1 (12.23 g) were significantly less than control. Dry weight of the root was significantly superior in *Glomus* 2 (34.99 g), *Glomus* 3 (34.41 g), *Glomus* 4 (33.81 g) and *Glomus* 1 (33.40 g) than control (27.62 g). *Glomus* 5 (31.34 g), *Glomus* 6 (29.08 g) and *Acaulospora* 1 (26.62 g) were at par with control.

***Phosphorus*:** Phosphorus uptake per plant was significantly more in *Glomus* 1 (110.767 mg), *Glomus* 2 (86.423 mg), *Glomus* 3 (84.143 mg), *Glomus* 5 (82.943 mg), *Glomus* 4 (80.703 mg), *Acaulospora* 1 (80.557 mg) and *Glomus* 6 (78.737) than control (56.043).

In general, *Glomus* 4 and *Glomus* 5 significantly increased shoot length of Lasoda. No treatment significantly increased collar diameter. *Glomus* 4, *Glomus* 5 and *Glomus* 1 significantly increased fresh shoot weight. No significant difference among treatments were recorded in dry shoot weight, *Glomus* 2 and *Glomus* 4 significantly increased fresh root weight, *Glomus* 2, *Glomus* 3, *Glomus* 4 and *Glomus* 1 significantly increased dry root weight and all the treatments significantly increased P uptake per plant.

4.5 Build up of VAM Colonization in Aonla, Ber and Chironji:

Data on colonization of Aonla, Ber and Chironji after 2, 3, 4 and 5 months by *Acaulospora* 1 are presented in Table 4.24. Formation of arbuscules and vesicles after inoculation with *Acaulospora* 1 was poor in all tested combinations. Good amount of extrametrical hyphae was recorded in all treatments. Spores in extrametrical hyphae, spores formed within the root and presence of sporocarp was not recorded in tested hosts. Maximum colonization index was recorded in Chironji, followed by Ber and Aonla. The

index values were quite low. Spore population per 100 g in rhizosphere of Ber and Aonla were very high as compared to Chironji.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 1 are presented in Table 4.25. Formation of arbuscules was poor in Ber and Chironji and absent in Aonla. Formation of vesicles and extrametrical hyphae was excellent in all treatments. Spores in extrametrical hyphae were absent and spore population per 100 gm soil was poor in all tree species. Formation of spores in root was maximum in Ber, followed by Aonla and Chironji. Among three tree species, maximum colonization index was recorded in Aonla followed by Ber and Chironji. Sporocarp formation maximum in Ber followed by Aonla and Chironji.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 2 are presented in Table 4.26. Formation of arbuscules and vesicles was poor in all tree species. Good amount of extrametrical hyphae with spores were recorded in all treatments. Spores in root were absent in all tested tree species. Among three tree species, maximum colonization index was recorded in Ber, followed by Aonla and Chironji. Spore counts per 100 gm soil were absent in Aonla and Chironji, poor in Ber. Formation of sporocarp was maximum in Aonla, followed by Ber and Chironji.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 3 are presented in Table 4.27. Formation of arbuscules was poor in Aonla and Chironji, absent in Ber. Vesicles formation was excellent in Ber and good in Aonla and Chironji. Presence of extrametrical hyphae was excellent in Aonla and Ber, good in Chironji. Spores in extrametrical hyphae were absent in all tested tree species. Spores in root were maximum in Aonla, followed by Ber and Chironji. Maximum colonization index was recorded in Ber, followed by Aonla and Chironji. Maximum spores counts per 100 gm soil was recorded in Aonla, followed by Chironji and absent in Ber. Sporocarp formation was good in Ber, poor in Aonla and absent in Chironji.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 4 are presented in Table 4.28. Formation of arbuscules was poor in Aonla, Ber and Chironji. Vesicles formation was excellent in Aonla and Ber, good in Chironji. Formation of extrametrical hyphae was maximum in Ber, followed by Aonla and Chironji. Formation of spores in extrametrical hyphae was absent in all tree species. Good amount of spore formation in root was recorded in Aonla and Ber, it was absent in Chironji. Maximum colonization index was recorded in Aonla, followed by Ber and Chironji. Spores counts per 100 gm soil were nil in all treatments. Sporocarp formation was poor in Ber and Chironji and it was absent in Aonla.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 5 are presented Table in 4.29. Formation of arbuscules was poor in all treatments. Vesicles formation was good in Aonla and Ber, poor in Chironji. Formation of extrametrical hyphae were recorded in all tested tree species. Spores in extrametrical hyphae were absent in all treatments. Formation of spores in root was poor in Aonla and absent in Ber and Chironji. Maximum colonization index was recorded in Aonla followed by Ber and Chironji. Spore counts per 100 gm soil were nil after sieving in all tested tree species. Sporocarp formation was poor in Aonla and Ber, absent in Chironji.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 6 are presented in Table 4.30. Formation of arbuscules was poor in Aonla and Ber and absent in Chironji. Vesicles formation was good in Aonla and poor in Ber and Chironji. Formation of extrametrical hyphae was excellent in Ber, good in Aonla and poor in Chironji. Spores in extrametrical hyphae were absent in all treatments. Formation of spores in root was poor in Ber and absent in Aonla and Chironji. Maximum colonization index was recorded in Ber, followed by Aonla and Chironji. Spores were not obtained on test sieves in all tested tree species. Sporocarp formation was good in Ber and Aonla and it was absent in Chironji.

Table 4.24 Build up of VAM colonization in selected minor fruit trees after inoculation with *Acaulospora* 1

Character	Fruit tree	Observations after			
		Two month	Three month	Four month	Five month
Arbuscules*	Aonla	+	-	+	-
	Ber	+	-	+	+
	Chironji	+	-	-	-
Vesicles*	Aonla	-	-	+	-
	Ber	-	-	-	-
	Chironji	+	-	-	-
Extrametrical hyphae*	Aonla	++	+	+	++
	Ber	++	+	+	+
	Chironji	-	+	+	+
Spores in extrametrical hyphae*	Aonla	-	-	-	-
	Ber	-	-	-	-
	Chironji	-	-	-	-
Spores in root*	Aonla	-	-	-	-
	Ber	-	-	-	-
	Chironji	-	-	-	-
Colonization index	Aonla	1.1	0.0	2.3	0.0
	Ber	4.5	0.0	1.5	0.8
	Chironji	8.9	0.0	1.5	0.5
Spore count per 100 g soil	Aonla	1191	1890	1320	488
	Ber	3177	3315	2257	1081
	Chironji	0.0	14	11	20
Sporocarp*	Aonla	-	-	-	-
	Ber	-	-	-	-
	Chironji	-	-	-	-

* - Absent + Present ++ Good +++ Excellent

Table 4.25 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 1

Characters	Fruit tree	Observations after			
		Two month	Three month	Four month	Five month
Arbuscules*	Aonla	-	-	-	+
	Ber	+	-	-	-
	Chironji	+	-	-	-
Vesicles*	Aonla	+++	+++	+++	+++
	Ber	+++	++	++	++
	Chironji	+++	-	-	+
Extrametrical hyphae*	Aonla	+++	++	++	++
	Ber	++	++	++	++
	Chironji	+++	++	++	++
Spores in extrametrical hyphae*	Aonla	-	-	-	-
	Ber	-	-	-	-
	Chironji	-	-	-	-
Spores in root*	Aonla	+	+	+	+
	Ber	+	++	++	++
	Chironji	-	+	+	++
Colonization index	Aonla	53.1	35.6	35.6	26.3
	Ber	42.2	15.9	15.9	15.3
	Chironji	42.5	1.2	1.3	7.5
Spore count per 100 g soil	Aonla	6.0	0	0	0.0
	Ber	0.0	0	0	0.0
	Chironji	0.0	0	0	7.0
Sporocarp*	Aonla	+	-	-	+
	Ber	-	+	++	+
	Chironji	-	-	-	+

* - Absent + Present ++ Good +++ Excellent

Table 4.26 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 2

Characters	Fruit tree	Observations after			
		Two month	Three month	Four month	Five month
Arbuscules*	Aonla	-	+	+	+
	Ber	+	-	-	++
	Chironji	+	-	-	+
Vesicles*	Aonla	-	-	-	++
	Ber	-	-	-	+
	Chironji	++	-	-	+
Extrametrical hyphae*	Aonla	++	++	++	++
	Ber	++	++	++	++
	Chironji	+	++	++	++
Spores in extrametrical hyphae*	Aonla	++	+	+	+
	Ber	++	+	+	+
	Chironji	+	+	+	+
Spores in root*	Aonla	-	-	-	-
	Ber	-	-	-	-
	Chironji	-	-	-	-
Colonization index	Aonla	8.3	0.5	0.5	14.1
	Ber	2.7	0.2	0.2	19.7
	Chironji	13.1	0.0	0.0	3.6
Spore count per 100 g soil	Aonla	0.0	0.0	0.0	0.0
	Ber	3.0	0.0	0.0	0.0
	Chironji	0.0	0.0	0.0	0.0
Sporocarp*	Aonla	-	+	+	+
	Ber	-	+	+	+
	Chironji	-	-	-	+

* - Absent + Present ++ Good +++ Excellent

Table 4.27 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 3

Characters	Fruit tree	Observations after			
		Two month	Three month	Four month	Five month
Arbuscules*	Aonla	-	-	-	+
	Ber	-	-	-	-
	Chironji	-	-	-	+
Vesicles*	Aonla	++	+	+	++
	Ber	+++	++	++	+++
	Chironji	+	-	+	++
Extrametrical hyphae*	Aonla	++	++	++	++
	Ber	+++	++	++	++
	Chironji	+	+	+	++
Spores in extrametrical hyphae*	Aonla	-	-	-	-
	Ber	-	-	-	-
	Chironji	-	-	-	-
Spores in root*	Aonla	+	++	++	++
	Ber	-	+	+	+
	Chironji	+	+	+	-
Colonization index	Aonla	17.7	8.0	8.0	21.4
	Ber	34.8	18.6	17.9	33.4
	Chironji	9.9	0.0	5.8	22.8
Spore count per 100 g soil	Aonla	0.0	18	15	0.0
	Ber	0.0	0.0	0.0	0.0
	Chironji	30	10	4	0.0
Sporocarp*	Aonla	-	-	-	+
	Ber	+	++	+	+
	Chironji	-	-	-	-

* - Absent + Present ++ Good +++ Excellent

Table 4.28 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 4

Characters	Fruit tree	Observations after			
		Two month	Three month	Four month	Five month
Arbuscules*	Aonla	-	+	+	-
	Ber	-	+	+	-
	Chironji	-	+	+	-
Vesicles*	Aonla	++	+	++	++
	Ber	++	+	++	+++
	Chironji	+	-	+	++
Extrametrical	Aonla	++	++	++	++
hyphae*	Ber	++	+++	+++	++
	Chironji	+	+	+	++
Spores in	Aonla	-	-	-	-
extrametrical	Ber	-	-	-	-
hyphae*	Chironji	-	-	-	-
Spores in root*	Aonla	+	+	+	++
	Ber	-	+	+	+
	Chironji	-	-	-	-
Colonization	Aonla	20.8	5.8	20.2	15.8
index	Ber	28.1	1.4	5.6	26.3
	Chironji	5.5	0.0	1.5	10.5
Spore count per	Aonla	0.0	0.0	0.0	0.0
100 g soil	Ber	0.0	0.0	0.0	0.0
	Chironji	0.0	0.0	0.0	0.0
Sporocarp*	Aonla	-	-	-	-
	Ber	+	-	-	+
	Chironji	-	-	-	+

* - Absent + Present ++ Good +++ Excellent

Table 4.29 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 5

Characters	Fruit tree	Observations after			
		Two month	Three month	Four month	Five month
Arbuscules*	Aonla	-	+	+	-
	Ber	-	-	-	+
	Chironji	+	-	-	+
Vesicles*	Aonla	-	++	+	+++
	Ber	-	-	-	+++
	Chironji	-	-	-	+
Extrametrical	Aonla	+	++	++	++
hyphae*	Ber	++	++	++	++
	Chironji	+	+	+	+
Spores in	Aonla	-	-	-	-
extrametrical	Ber	-	-	-	-
hyphae*	Chironji	-	-	-	-
Spores in root*	Aonla	-	-	-	+
	Ber	-	-	-	-
	Chironji	-	-	-	-
Colonization	Aonla	0.0	13.0	13.0	55.6
index	Ber	2.5	0.2	0.2	56.4
	Chironji	13.9	0.0	0.0	4.5
Spore count per	Aonla	0.0	0.0	0.0	0.0
100 g soil	Ber	0.0	0.0	0.0	0.0
	Chironji	0.0	0.0	0.0	0.0
Sporocarp*	Aonla	-	-	-	+
	Ber	-	-	+	++
	Chironji	-	-	-	-

* - Absent + Present ++ Good +++ Excellent

Table 4.30 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 6

Characters	Fruit tree	Observations after			
		Two month	Three month	Four month	Five month
Arbuscules*	Aonla	-	+	-	-
	Ber	+	-	-	+
	Chironji	-	-	-	-
Vesicles*	Aonla	-	+	+	++
	Ber	-	+	+	+
	Chironji	+	-	-	+
Extrametrical	Aonla	+	+	+	++
hyphae*	Ber	+++	+++	+++	+++
	Chironji	-	+	+	+
Spores in	Aonla	-	-	-	-
extrametrical	Ber	-	-	-	-
hyphae*	Chironji	-	-	-	-
Spores in root*	Aonla	-	-	-	-
	Ber	-	+	+	+
	Chironji	-	-	-	-
Colonization	Aonla	0.5	1.5	1.6	6.6
index	Ber	2.0	0.8	0.8	10.2
	Chironji	2.2	0.0	0.0	3.3
Spore count per	Aonla	0.0	0.0	0.0	0.0
100 g soil	Ber	0.0	0.0	0.0	0.0
	Chironji	0.0	0.0	0.0	0.0
Sporocarp*	Aonla	-	+	+	++
	Ber	+	++	++	++
	Chironji	-	+	+	+

* - Absent + Present ++ Good +++ Excellent

4.6 Build up of VAM colonization in different crops in different seasons:

Build up of VAM colonization of different crops in different seasons (Rabi, Zaid and Kharif) was studied to identifying suitable conditions for maintenance of different VAM cultures.

4.6.1 *Acaulospora* 1: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Acaulospora* 1 are presented in Table 4.31. Presence of arbuscules, vesicles and extrametrical hyphae was noticed in all tested crops. Formation of arbuscules was maximum in maize, formation of vesicles was maximum in black gram and green gram and good amount of extrametrical hyphae were recorded in gram, maize and pea. Spores in extrametrical hyphae and roots were absent in rhizosphere of all crops. Colonization index was maximum in maize. It was less then 20% in other crops. Excellent sporulation was noticed in maize, black gram and green gram during Kharif season. Formation of sporocarp was absent in rhizosphere of all tested crops. Maize, black gram and green gram were identified as good host for the fungus.

4.6.2 *Glomus* 1: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 1 are presented in Table 4.32. Presence of arbuscules, vesicles and extrametrical mycelium was recorded in all tested combinations. Formation of spores in extrametrical mycelium was absent but spores in roots were noticed in all crops. Maximum colonization index were recorded in maize during all seasons (Rabi, Zaid and Kharif) followed by black gram, green gram, pea, wheat and gram. Spores were not obtained after sieving. Sporocarp formation was recorded in rhizosphere in maize, green gram and black gram. It was absent in rhizosphere of gram, pea and wheat. In general, culture of this fungus could be maintained on maize with ease.

4.6.3 *Glomus* 2: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 2 are presented in Table 4.33. Formation of arbuscules was noticed in maize, wheat, pea and

gram. The fungus formed vesicles in the roots of all tested crops. Formation of extrametrical hyphae was seen in all tested combinations. The extrametrical hyphae were more in maize, green gram and black gram than gram, pea and wheat. Presence of spores in extrametrical hyphae was recorded in maize, green gram, black gram and gram. Formation of spores in root was not noticed. Spores were not obtained after sieving and spore counts were nil in all tested combinations. Among all tested crops, maximum colonization index was recorded in maize during all seasons. In other crops it was less then 10%. Presence of sporocarp was noticed in rhizosphere of maize, black gram and green gram. Maize was recognized as suitable host for the fungus.

4.6.4 *Glomus* 3: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 3 are presented in Table 4.34. Arbuscules formation was present in maize, green gram, black gram, pea, wheat and gram but in maize the rate of arbuscules formation was faster than others crops. Similarly by vesicles formation in maize was more than other crops. Formation of extrametrical hyphae were present in all tested combinations. The extrametrical hyphae was more in maize, black gram and green gram than gram, pea and wheat. Spores in extrametrical hyphae were not noticed in all tested combinations. Formation of spores in root was more in maize, black gram, green gram as compare to gram, pea and wheat. Spore count after sieving was nil in all tested crops. Among all tested crops, maximum colonization index was recorded in maize followed by green gram, black gram. In others crop colonization index was less than 20%. Presence of sporocarp was recorded in maize, black gram, green gram.

4.6.5 *Glomus* 4: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 4 are presented in Table 4.35. Abuscules were present in all tested crops, except gram. Formation of arbuscules was maximum in maize. Vesicles and extrametrical hyphae were noticed in all tested combinations. Vesicle formation was more in pea and maize than black gram, green gram, gram and wheat. Good amount of

extrametrical hyphae were noticed in black gram, maize, green gram, pea, wheat and gram. Spores in extrametrical hyphae were absent in rhizosphere of all crops. Spores in root were present in all tested combinations, which were maximum in pea and maize. Colonization index was maximum in pea (15.58%), followed by maize (winter: 12.67%, summer: 19.67%, rain: 60.3%) black gram (summer: 8.33%, rain: 7.5%), green gram (summer: 8.36%, rain: 4.7%), wheat (3.47%) and gram (2.60%). Sporocarps were present in black gram, maize and green gram. Spore counts after sieving were absent in all tested combinations. Maize was recognized as good host.

4.6.6 *Glomus* 5: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 5 are presented in Table 4.36. Formation of arbuscules was present in maize, pea, wheat, gram and green gram. Arbuscules formation was absent in black gram. Presence of vesicles and extrametrical hyphae were noticed in all tested crops and spore formation in roots was recorded in maize, black gram and green gram. Colonization index was maximum in maize (winter: 21.56%, summer: 16.91%, rain: 57.7%), followed by pea (9.86%), black gram (summer: 7.35%, rain: 14.2%), green gram (summer: 10.60%, rain: 19.7%), wheat (4.51%) and gram (2.19%). Spore count after sieving was zero in all tested combinations. Sporocarp formation was recorded only in maize during month of OctoBer. Maize was identified as good host for the fungus.

4.6.7 *Glomus* 6: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 6 are presented in Table 4.37. Presence of arbuscules and vesicles was noticed in all tested crops, except gram. Presence of extrametrical hyphae was noticed in all tested crops, except wheat. Spores in extrametrical hyphae were noticed during Zaid and Kharif, but were absent during Rabi in all tested crops. Spores were present in root of all tested crops in small numbers except wheat. Maximum colonization index was recorded in maize (Rabi: 15.04%, Zaid: 10.08%, Kharif: 54.4%), while its value was less then 10% in other crops. Spores were

not obtained after sieving in all crops. Sporocarps were recorded during Zaid and Kharif but were absent during Rabi season in tested crops. Good amount of sporocarp formation was recorded in maize, black gram and green gram. Maize was recorded as suitable plant host for the fungus during Zaid and Kharif seasons.

Table 4.31 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Acaulospora* 1

Character	Crops	Observations after				
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops						
Arbuscules*	Gram	+	-	-	-	-
	Maize	-	++	+++	-	+++
	Pea	-	-	+	+++	+
	Wheat	-	+	+	-	+
Vesicles*	Gram	-	+	++	-	-
	Maize	-	+	-	++	++
	Pea	+	+	++	+	+
	Wheat	-	+	-	-	-
Extrametrical hyphae*	Gram	-	+	++	-	+
	Maize	-	+	-	++	++
	Pea	+	+	++	+	-
	Wheat	-	+	-	-	-
Spores in extrametrical hyphae*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Spores in root*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Colonization index	Gram	5.2	7.3	12.3	14.3	12.4
	Maize	6.4	32.7	78.4	79.7	56.9
	Pea	2.8	14.8	15.3	18.2	9.1
	Wheat	2.8	14.2	14.1	6.3	6.4
Spore count per 100 g soil	Gram	0	0	20	4	14
	Maize	0	0	0	0	1.5
	Pea	0	0	18	25	15
	Wheat	0	0	21.2	2.0	3
Sporocarp*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Zaid (summer) crops						
Arbuscules*	Maize	+++	+++	+	+++	+++
	Black gram	-	+	-	-	+
	Green gram	+	+	-	-	+
Vesicles*	Maize	+	+	+	+	-
	Black gram	+++	++	+	+	-
	Green gram	+++	++	+	+	-
Extrametrical hyphae*	Maize	+	+	++	+	+
	Black gram	+	+	+	+	-
	Green gram	+	+	++	++	-
Spores in extrametrical hyphae*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	-	-
Spores in root	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	-	-

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Colonization index	Maize	44.1	10	3.0	12.5	18.4
	Black gram	30.5	17.8	4.9	5.3	2.2
	Green gram	34.4	23.3	7.1	6.4	1.4
Spore count per 100 g soil	Maize	4	6	0	0	16
	Black gram	1	3	0	0	0.0
	Green gram	1	0	0	0	2.0
Sporocarp*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	-	-
<u>Kharif (rainy) crops</u>						
Arbuscules*	Maize	+++	++	+++		
	Black gram	-	+	+		
	Green gram	+++	+	+		
Vesicles*	Maize	-	+++	++		
	Black gram	+	+++	+++		
	Green gram	-	++	+		
Extrametrical hyphae*	Maize	++	+++	++		
	Black gram	++	+	+		
	Green gram	++	++	+		
Spores in extrametrical hyphae*	Maize	-	-	-		
	Black gram	-	-	-		
	Green gram	-	-	-		
Spores in root*	Maize	+	++	+++		
	Black gram	-	+	+		
	Green gram	-	-	-		
Colonization index	Maize	29.4	56.6	61.7		
	Black gram	15.3	54.9	53.3		
	Green gram	22.0	22.2	12.3		
Spore count per 100 g soil	Maize	0	0	0		
	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize	-	++	++		
	Black gram	-	+	-		
	Green gram	-	+	-		

* - Absent + Present ++ Good +++ Excellent

Table 4.32 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 1

Character	Crops	Observations after				
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops						
Arbuscules*	Gram	++	-	-	+	-
	Maize	++	+++	+++	+++	+++
	Pea	++	+	-	-	++
	Wheat	-	+	+	-	-
Vesicles*	Gram	+	++	+++	+++	++
	Maize	+	+++	++	+++	+++
	Pea	+	++	+++	+++	+++
	Wheat	+	++	+	+	+
Extrametrical hyphae*	Gram	+	+	+	+	-
	Maize	++	++	++	+	+
	Pea	+	+	+	+	-
	Wheat	+	+	-	+	-
Spores in extrametrical hyphae*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Spores in root*	Gram	-	-	-	++	+
	Maize	-	-	-	++	+++
	Pea	-	-	+	++	+
	Wheat	-	-	-	-	+
Colonization index	Gram	8.9	28.6	31.6	17.5	18.5
	Maize	11.9	33.9	72.2	90.6	56.9
	Pea	16.1	31.1	36.3	44.4	48.9
	Wheat	8.9	16.4	9.5	12.2	3.9
Spore count per 100 g soil	Gram	0	0	0	0	0
	Maize	0	0	0	0	10
	Pea	0	0	0	0	-
	Wheat	0	0	0	0	-
Sporocarp*	Gram	-	-	-	-	-
	Maize	-	+	+	+	+
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Zaid (summer) crops						
Arbuscules*	Maize	+	+++	++	+++	+++
	Black gram	-	-	+	-	-
	Green gram	+	++	-	-	-
Vesicles*	Maize	+	+++	+	++	++
	Black gram	++	++	++	++	-
	Green gram	++	++	++	+	+++
Extrametrical hyphae*	Maize	-	+	+	++	+++
	Black gram	+	+	+++	+	-
	Green gram	+	+	++	+	+
Spores in extrametrical hyphae*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	-	-
Spores in root*	Maize	-	+	+	+	++
	Black gram	-	+	+++	-	+
	Green gram	-	++	++	-	+

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Colonization index	Maize	15.5	50.9	12.4	23.1	35.0
	Black gram	17.0	19.3	12.4	10.5	0.6
	Green gram	46.6	28.3	6.9	6.4	29.6
Spore count per	Maize	0	0	0	0	0
100 g soil	Black gram	0	0	0	0	0
	Green gram	0	0	0	0	0
Sporocarp*	Maize	-	-	+	-	-
	Black gram	-	-	+	-	-
	Green gram	-	-	+	-	-
Kharif (Rainy) crops						
Arbuscules*	Maize	+++	++	+++		
	Black gram	-	+	+		
	Green gram	+++	+	+		
Vesicles*	Maize	-	+++	++		
	Black gram	+	+++	+++		
	Green gram	-	++	+		
Extrametrical hyphae*	Maize	++	+++	++		
	Black gram	++	+	+		
	Green gram	++	++	+		
Spores in extrametrical	Maize	-	-	-		
hyphae*	Black gram	-	-	-		
	Green gram	-	-	-		
Spores in root*	Maize	+	++	+++		
	Black gram	-	+	+		
	Green gram	-	-	-		
Colonization index	Maize	29.4	56.6	61.7		
	Black gram	15.3	54.9	53.3		
	Green gram	22.0	22.2	12.3		
Spore count per	Maize	0	0	0		
100 g soil	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize	-	++	++		
	Black gram	-	+	-		
	Green gram	-	+	-		

* - Absent + Present ++ Good +++ Excellent

Table 4.33 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 2

Character	Crops	Observations after				
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops						
Arbuscules*	Gram	+	-	+	-	-
	Maize	+++	+++	+++	+++	+++
	Pea	+	-	+	+	-
	Wheat	+	+	+	-	-
Vesicles*	Gram	-	+	+	+	-
	Maize	+	+	++	+	+
	Pea	-	+	+	+	-
	Wheat	-	+	+	-	-
Extrametrical hyphae*	Gram	+	+	+	-	-
	Maize	+	+++	++	++	+++
	Pea	-	+	+	-	-
	Wheat	-	-	+	-	-
Spores in extrametrical hyphae*	Gram	-	-	+	-	-
	Maize	-	+	++	++	++
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Spores in root*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Colonization index	Gram	4.7	5.8	1.1	0	1.7
	Maize	41.9	48.9	65	51.3	46.6
	Pea	1.1	7.5	9.5	6.1	2.0
	Wheat	41.1	11.3	11.9	2.5	2.5
Spore count per 100 g soil	Gram	0	0	0	0	0
	Maize	0	0	0	0	0
	Pea	0	0	0	0	0
	Wheat	0	0	0	0	0
Sporocarp*	Gram	-	-	-	-	-
	Maize	-	-	-	+	++
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Zaid (summer) crops						
Arbuscules*	Maize	++	++	+	++	++
	Black gram	-	-	-	-	++
	Green gram	-	-	-	-	+
Vesicles*	Maize	++	+	+	-	-
	Black gram	-	+	+	-	-
	Green gram	-	-	+	+	-
Extrametrical hyphae*	Maize	+	+	+	+	+
	Black gram	+	++	+++	++	++
	Green gram	+	+	+++	++	+
Spores in extrametrical hyphae*	Maize	-	+	-	-	-
	Black gram	-	+	++	-	+
	Green gram	+	+	++	-	+
Spores in root*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	-	-

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Colonization index	Maize	12.8	13.75	2.5	13.3	20.0
	Black gram	5.6	7.5	8.3	11.1	17.5
	Green gram	3.2	7.3	3.2	1.9	5.6
Spore count per	Maize	0	0	0	0	0
100 g soil	Black gram	0	0	0	0	0
	Green gram	0	0	0	0	0
Sporocarp*	Maize	-	-	-	-	-
	Black gram	-	-	++	-	-
	Green gram	-	-	+	-	-
Kharif (rainy) crops						
Arbuscules*	Maize	++	+++	+++		
	Black gram	-	-	+		
	Green gram	+	-	+		
Vesicles*	Maize	+	+	++		
	Black gram	-	+	-		
	Green gram	+	+	+		
Extrametrical hyphae*	Maize	+	+++	+++		
	Black gram	++	+	+		
	Green gram	++	+++	++		
Spores in extrametrical	Maize	-	++	++		
hyphae*	Black gram	+	-	+		
	Green gram	+	++	+		
Spores in root*	Maize	-	-	-		
	Black gram	-	-	-		
	Green gram	-	-	-		
Colonization index	Maize	26.4	58.1	59.4		
	Black gram	0.0	2.5	3.3		
	Green gram	2.8	4.0	4.7		
Spore count per 100 g	Maize	0	0	0		
soil	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize	-	++	+++		
	Black gram	-	-	++		
	Green gram	-	-	++		

* - Absent + Present ++ Good +++ Excellent

Table 4.34 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 3

Character	Crops	Observations after				
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops						
Arbuscules*	Gram	+	-	-	+	+
	Maize	+	-	+	+	+
	Pea	-	+	+	+	-
	Wheat	-	+	+	-	-
Vesicles*	Gram	-	-	-	+	+
	Maize	-	+	+++	+++	+++
	Pea	-	-	-	+	+
	Wheat	-	+	+	+	-
Extrametrical hyphae*	Gram	-	-	-	++	+
	Maize	+	+	+	++	+
	Pea	-	-	+	++	+
	Wheat	-	-	+	-	-
Spores in extrametrical hyphae*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Spores in root*	Gram	-	-	-	++	+
	Maize	-	-	-	++	++
	Pea	-	-	-	++	+
	Wheat	-	-	-	-	+
Colonization index	Gram	1.7	0	0	5.6	3.6
	Maize	14.7	16.6	52.7	46.7	55.5
	Pea	0.0	0.78	0.93	6.5	5.3
	Wheat	12.5	16.3	3.9	3.75	1.7
Spore count per 100 g soil	Gram	4	0	0	3	0
	Maize	0	0	0	0	0
	Pea	0	0	0	4	0
	Wheat	0	0	0	0	0
Sporocarp*	Gram	-	-	-	-	-
	Maize	-	-	-	+	+
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Zaid (summer) crops						
Arbuscules*	Maize	++	++	+	++	++
	Black gram	+	-	-	-	-
	Green gram	+	+	-	-	-
Vesicles*	Maize	-	+	+++	+++	+++
	Black gram	+++	+	+	+	-
	Green gram	+++	++	+	+	++
Extrametrical hyphae*	Maize	+	+	++	+	++
	Black gram	++	+	++	++	++
	Green gram	++	+	+++	++	++
Spores in extrametrical hyphae*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	-	-
Spores in root*	Maize	-	+	+	+	++
	Black gram	-	+	+++	+	+
	Green gram	-	+	+++	+	+

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Colonization index	Maize	23.9	27.8	8.6	21.3	32.5
	Black gram	57.0	13.3	8.8	2.4	0.5
	Green gram	62.2	16.1	12.4	1.25	17.2
Spore count per	Maize	0	0	5	0	0
100 g soil	Black gram	0	0	5	20	0
	Green gram	0	0	0	25	0
Sporocarp*	Maize	-	-	+	-	-
	Black gram	-	+	+	-	-
	Green gram	-	+	+	-	-
Kharif (rainy) crops						
Arbuscules*	Maize	++	++	++		
	Black gram	++	-	-		
	Green gram	++	+	-		
Vesicles*	Maize	+	+++	+++		
	Black gram	++	+++	+++		
	Green gram	-	+++	++		
Extrametrical hyphae*	Maize	+	+++	+++		
	Black gram	+	++	++		
	Green gram	+	++	++		
Spores in extrametrical	Maize	-	-	-		
hyphae*	Black gram	-	-	-		
	Green gram	-	-	-		
Spores in root*	Maize	-	++	+++		
	Black gram	-	+	+		
	Green gram	-	-	+		
Colonization index	Maize	26.4	38.3	45.2		
	Black gram	22.2	37.3	35.3		
	Green gram	12.1	35.8	22.8		
Spore count per	Maize	0	0	0		
100 g soil	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize	-	-	++		
	Black gram	-	-	+		
	Green gram	-	-	-		

* - Absent + Present ++ Good +++ Excellent

Table 4.35 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 4

Character	Crops	Observations after				
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops						
Arbuscules*	Gram	-	-	-	-	-
	Maize	+	+	++	++	++
	Pea	+	-	-	-	-
	Wheat	+	+	-	+	+
Vesicles*	Gram	-	+	-	+	+
	Maize	+	+	++	+	+
	Pea	-	++	+++	++	+
	Wheat	-	+	+	+	+
Extrametrical hyphae*	Gram	+	-	-	-	-
	Maize	-	+	+	+	++
	Pea	-	-	+	++	+
	Wheat	+	-	-	+	-
Spores in extrametrical hyphae*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Spores in root*	Gram	-	-	-	+	+
	Maize	-	+	+	-	+
	Pea	-	-	+	+++	-
	Wheat	-	-	-	+	-
Colonization index	Gram	0	4.2	0.5	4.2	4.1
	Maize	0.9	13.8	24.4	8.0	16.25
	Pea	2.8	15.8	29.4	15.8	14.1
	Wheat	1.25	4.9	5.6	2.8	2.8
Spore count per 100 g soil	Gram	0	0	0	0	0
	Maize	0	0	0	0	0
	Pea	0	0	0	0	0
	Wheat	0	0	0	0	0
Sporocarp*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	+	-
	Wheat	-	-	-	-	-
Zaid (summer) crops		+	-	+	+	++
Arbuscules*	Maize	+	-	-	-	-
	Black gram	-	+	-	-	-
	Green gram	-	++	+	+++	++
Vesicles*	Maize	+	++	+	-	+
	Black gram	+	+	+	-	+
	Green gram	-	+	+	++	+++
Extrametrical hyphae*	Maize	+	+++	++	++	++
	Black gram	+	+	++	++	++
	Green gram	-	-	-	-	-
Spores in extrametrical hyphae*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	+	++
Spores in root*	Maize	-	+	+	+	-
	Black gram	-	+	-	+	-
	Green gram	7.4	13.6	9.68	29.38	38.3

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Colonization index	Maize	7.5	17.4	4.84	6.41	5.5
	Black gram	10.5	7.8	0.31	0.48	22.7
	Green gram	0	0	0	0	0
Spore count per	Maize	0	0	0	0	0
100 g soil	Black gram	0	0	0	0	0
	Green gram	-	-	-	-	-
Sporocarp*	Maize	-	+	+	-	-
	Black gram	-	-	-	-	-
	Green gram					
Kharif (rainy) crops						
Arbuscules*	Maize	++	+++	+++		
	Black gram	-	-	+		
	Green gram	+	-	+		
Vesicles*	Maize	+	+	++		
	Black gram	-	+	-		
	Green gram	+	+	+		
Extrametrical hyphae*	Maize	+	+++	+++		
	Black gram	++	+	+		
	Green gram	++	+++	++		
Spores in extrametrical	Maize	-	++	++		
hyphae*	Black gram	+	-	+		
	Green gram	+	++	+		
Spores in root*	Maize	-	-	-		
	Black gram	-	-	-		
	Green gram	-	-	-		
Colonization index	Maize	26.4	58.1	59.4		
	Black gram	0.0	2.5	3.3		
	Green gram	2.8	4.0	4.7		
Spore count per 100 g soil	Maize	0	0	0		
	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize	-	++	+++		
	Black gram	-	-	++		
	Green gram	-	-	++		

* - Absent + Present ++ Good +++ Excellent

Table 4.36 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 5

Character	Crops	Observations after				
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops						
Arbuscules*	Gram	-	+	-	-	-
	Maize	+	+	++	+++	+++
	Pea	+	+	+	+	-
	Wheat	-	-	+	-	-
Vesicles*	Gram	-	-	+	+	-
	Maize	-	+	+	-	+
	Pea	-	-	++	++	+
	Wheat	-	-	+	+	+
Extrametrical hyphae*	Gram	-	-	-	-	-
	Maize	-	-	+	-	-
	Pea	-	-	-	+	-
	Wheat	-	+	+	+	-
Spores in extrametrical hyphae*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Spores in root*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Colonization index	Gram	1.6	0.63	3.4	2.8	2.5
	Maize	2.1	10.0	19.2	35.9	40.6
	Pea	1.6	1.7	21.1	22.5	2.4
	Wheat	0.63	2.0	3.9	10.8	5.20
Spore count per 100 g soil	Gram	0	0	0	0	0
	Maize	0	0	0	0	0
	Pea	0	0	0	0	0
	Wheat	0	0	0	0	0
Sporocarp	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Zaid (summer) crops						
Arbuscules*	Maize	+++	+++	-	-	+
	Black gram	-	-	-	-	-
	Green gram	+	+	-	-	-
Vesicles*	Maize	+	+++	+	+	+
	Black gram	+	-	+	+	+
	Green gram	++	++	+	++	-
Extrametrical hyphae*	Maize	-	++	++	++	+++
	Black gram	+	+++	+	++	++
	Green gram	+	++	+	++	+
Spores in extrametrical hyphae*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	-	-
Spores in root*	Maize	-	-	-	-	-
	Black gram	-	+	+	-	-
	Green gram	-	+	+	-	-

... Continued

Colonization index	Maize	16.1	39.2	3.75	3.59	21.9
	Black gram	13.6	4.5	8.0	10.63	0.0
	Green gram	26.4	15	2.34	8.28	1.0
Spore count per	Maize	0	0	0	0	0
100 g soil	Black gram	0	0	0	0	0
	Green gram	0	0	0	0	0
Sporocarp*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	-	-
Kharif (rainy) crops						
Arbuscules*	Maize	++	++	+		
	Black gram	-	-	-		
	Green gram	-	+	-		
Vesicles*	Maize	+++	+++	+++		
	Black gram	-	++	++		
	Green gram	-	+++	++		
Extrametrical hyphae*	Maize	+	+	+++		
	Black gram	++	+	+		
	Green gram	+	+	+		
Spores in extrametrical	Maize	-	-	-		
hyphae*	Black gram	-	-	-		
	Green gram	-	-	-		
Spores in root*	Maize	-	-	+++		
	Black gram	-	-	-		
	Green gram	-	-	-		
Colonization index	Maize	31.4	40.8	57.7		
	Black gram	0.0	18.3	14.2		
	Green gram	4.8	29.2	19.7		
Spore count per	Maize	0	0	0		
100 g soil	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize	-	-	++		
	Black gram	-	-	-		
	Green gram	-	-	-		

* - Absent + Present ++ Good +++ Excellent

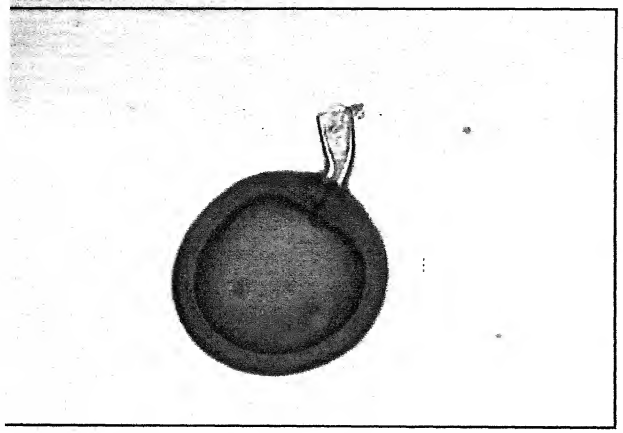
Table 4.37 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus 6*

Character	Crops	Observations after				
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops						
Arbuscules*	Gram	-	-	-	-	-
	Maize	+	+	++	+++	+
	Pea	+	-	-	-	-
	Wheat	+	+	-	-	-
Vesicles*	Gram	-	-	-	-	-
	Maize	+	+	+	+	+
	Pea	-	-	-	-	+
	Wheat	-	-	-	-	+
Extrametrical hyphae*	Gram	-	-	-	-	+
	Maize	-	-	+	+	+
	Pea	-	-	-	-	+
	Wheat	-	-	-	-	-
Spores in extrametrical hyphae*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Spores in root*	Gram	-	-	-	+	-
	Maize	-	-	+	+	+
	Pea	-	-	+	+	-
	Wheat	-	-	-	-	-
Colonization index	Gram	0.16	0.0	0.47	0.47	0.15
	Maize	3.0	17.8	23.3	23.3	7.8
	Pea	0.5	0.5	0.3	0.3	1.25
	Wheat	3.0	2.0	0.78	0.78	4.4
Spore count per 100 g soil	Gram	0	0	0	0	0
	Maize	0	0	0	0	0
	Pea	0	0	0	0	0
	Wheat	0	0	0	0	0
Sporocarp*	Gram	-	-	-	-	-
	Maize	-	-	-	-	-
	Pea	-	-	-	-	-
	Wheat	-	-	-	-	-
Zaid (summer) crops						
Arbuscules*	Maize	++	++	+	++	++
	Black gram	+	-	-	-	-
	Green gram	-	+	-	-	-
Vesicles*	Maize	-	++	-	-	+
	Black gram	+	+	+	+	+
	Green gram	+	+	-	-	-
Extrametrical hyphae*	Maize	-	+	+	++	++
	Black gram	+	++	++	+++	++
	Green gram	-	+	++	+	++
Spores in extrametrical hyphae*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	-	-	-	-
Spores in root*	Maize	-	-	-	-	-
	Black gram	-	-	-	-	-
	Green gram	-	+	+	-	-

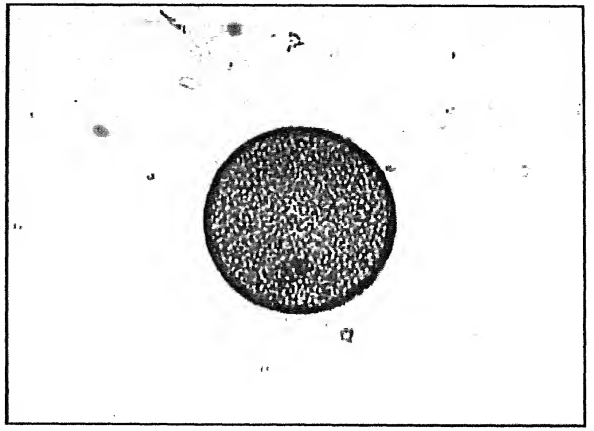
... Continued

Colonization index	Maize	26.9	26.7	3.1	12.8	20.9
	Black gram	6.9	8.1	0.63	1.71	5.6
	Green gram	4.5	4.3	0.0	0.31	1.3
Spore count per	Maize	0	0	0	0	0
100 g soil	Black gram	0	0	0	0	0
	Green gram	0	0	0	0	0
Sporocarp*	Maize	-	-	-	+	+
	Black gram	-	+	++	++	+
	Green gram	-	-	+	+	-
Kharif (rainy) crops						
Arbuscules*	Maize	+++	+++	+++		
	Black gram	-	-	+		
	Green gram	-	-	+		
Vesicles*	Maize	-	+	+		
	Black gram	+	+	+		
	Green gram	-	+	+		
Extrametrical hyphae*	Maize	++	+++	+++		
	Black gram	++	+++	++		
	Green gram	++	+	+++		
Spores in extrametrical	Maize	-	-	+		
hyphae*	Black gram	-	-	+		
	Green gram	-	-	+		
Spores in root*	Maize	-	-	+		
	Black gram	-	+	+		
	Green gram	-	-	-		
Colonization index	Maize	30.2	26.2	54.4		
	Black gram	1.4	26.1	5.9		
	Green gram	0.9	10.2	5.5		
Spore count per	Maize	0	0	0		
100 g soil	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize	-	++	++		
	Black gram	-	++	+		
	Green gram	-	+	+		

* - Absent + Present ++ Good +++ Excellent

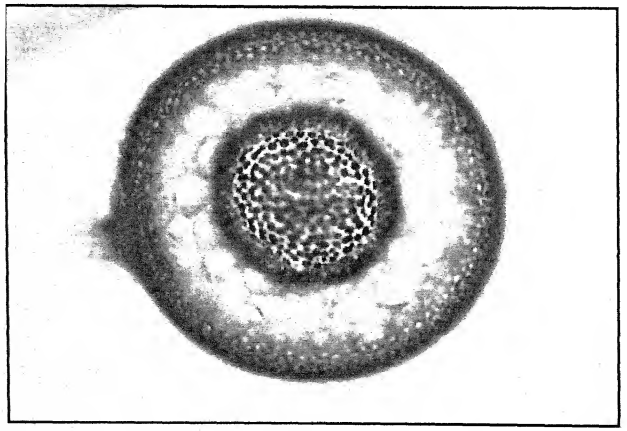


Glomus I

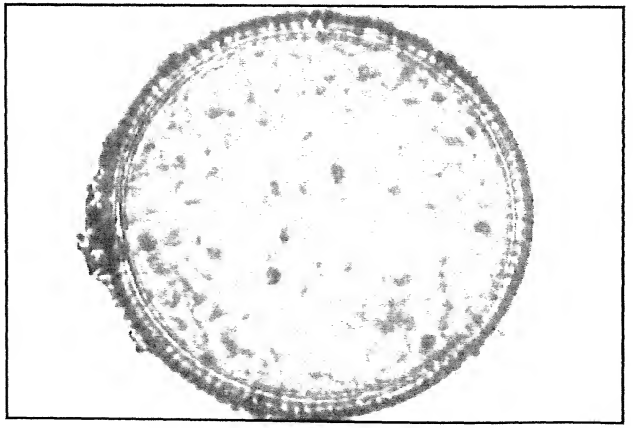


Glomus II

Glomus mosseae



Acaulospora I



Acaulospora II

Gigaspora white

Plate 1. Common VAM fungi under field conditions

Spore colour: Brown

Spore size:

Mean: 115 x 115 µ
Range: 108 – 127 µ

Composite wall width: 13.0 µ

No. of wall groups: 2

Muronym: A (U_o)B(UM)

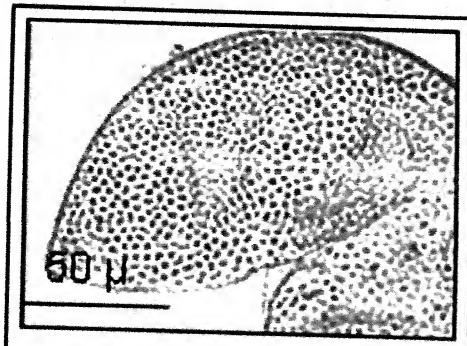
Hyphal terminus: Present

Wall reaction to Meltzer's reagent: Present

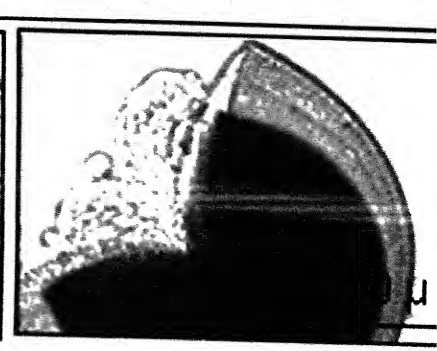
Spores formation within roots: Absent

Sporocarp: Absent

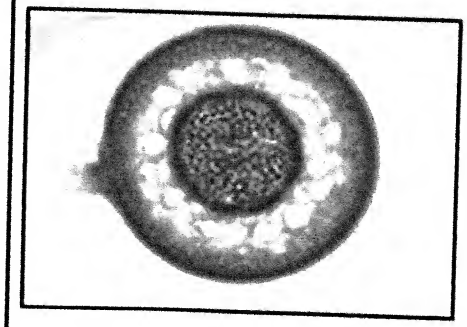
Surface ornamentation: Present



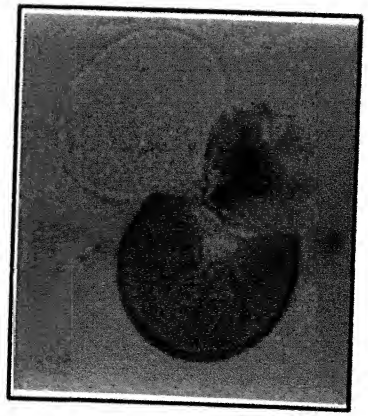
Spore



Reaction to Meltzer's reagent



Endospore



Hyphal terminus

Plate 2. Characteristics of *Acaulospora* 1

Spore colour: Dark yellow

Spore size:

Mean - 96 x 96 µ

Range - 84 – 120 x 86 – 125 µ

Composite wall width: 7.2 µ

No. of wall groups: 1

Muronym: ? A (L)

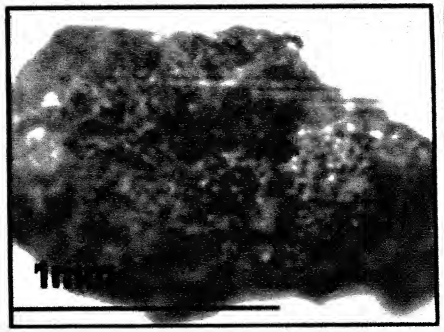
Attachment: Present

Wall reaction to Meltzer's reagent: Absent

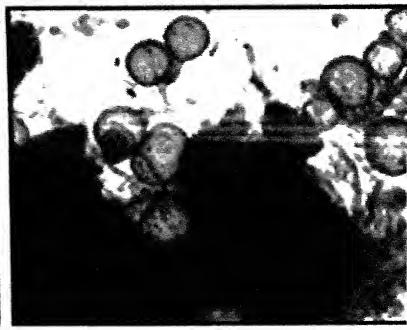
Spores formation within roots: Present

Sporocarp: Present

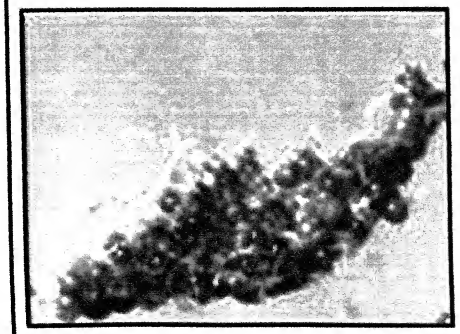
Colour of sporocarp: Blackish yellow



Spores in root



Spores in sporocarp



Sporocarp

Spore

Plate 3. Characteristics of *Glomus* 1

Spore colour: Light yellow

Spore size:

Mean: 49 x 49 µ
Range: 36 – 72 µ

Composite wall width: 3.5 µ

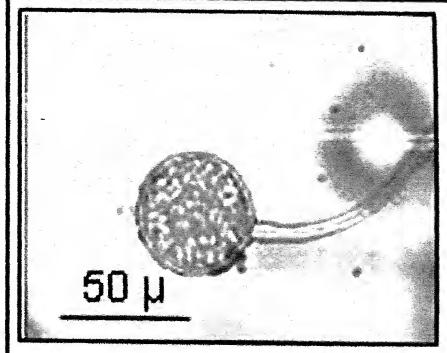
No. of wall groups: 1

Spores formation within roots: Absent

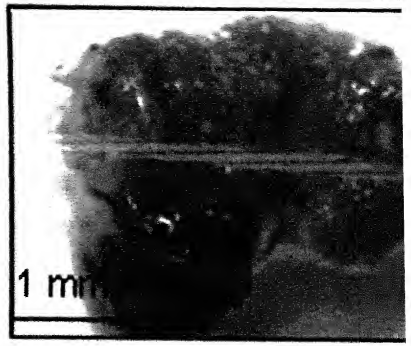
Spore with extra metricular hyphae: Present

Sporocarp: Present

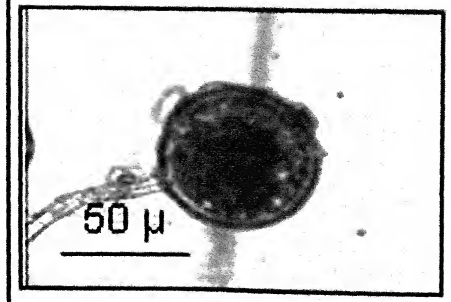
Colour of sporocarp: Light brownish yellow



Spore



Sporocarp



Reaction to Meltzer's reagent

Spore

Plate 4. Characteristics of *Glomus* 2

Spore colour: Yellow to light brown

Spore size:

Mean: 84 x 81 µ
Range: 60 – 124 x 55 – 120 µ

Composite wall width: 4.2 µ

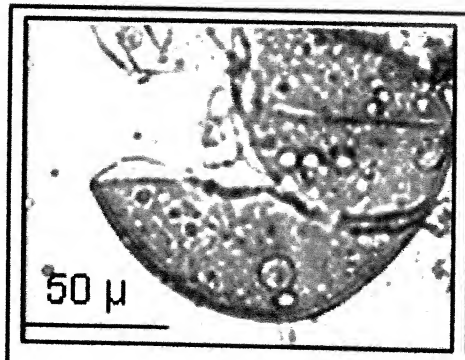
Number of wall groups: 1

Muronym: ? A (L)

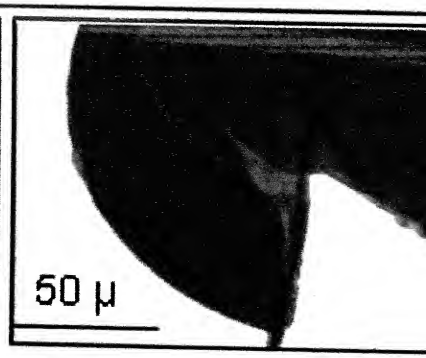
Spores formation within roots: Present

Sporocarp: Present

Colour of sporocarp: Yellow to brown



Spores in PVLG



Spores in Meltzer's

Spores in roots

Sporocarp

Plate 5. Characteristics of *Glomus* 3

Spore colour: Brownish yellow

Spore size:

Mean: 76 x 76 µ

Range: 38 – 115 x 43 – 103µ

Composite wall width: 5.0 µ

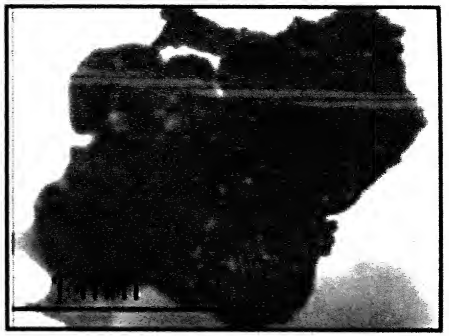
No. of wall groups: 1

Muronym: ? A (L)

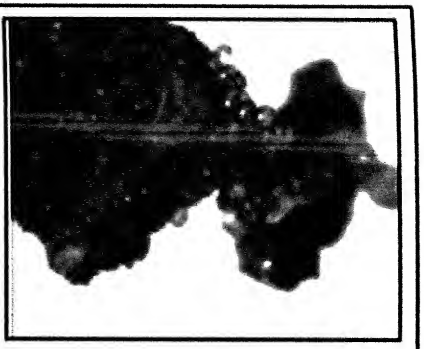
Spores formation within roots: Present

Sporocarp: Present

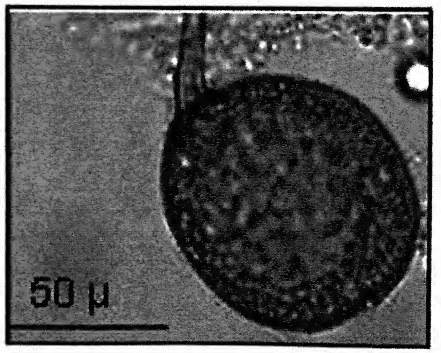
Colour of sporocarp: Yellow (Turmeric)



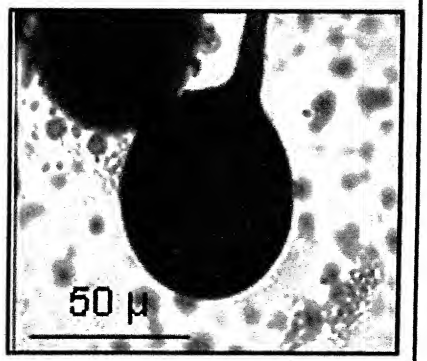
Sporocarp



Sporocarp with spores



Spore in PVLG



Spore in Meltzer's reagent

Plate 6. Characteristics of *Glomus* 4

Spore colour: Creamish yellow

Spore size:

Mean: 59 x 56 µ

Range: 36 – 96 x 33 – 76 µ

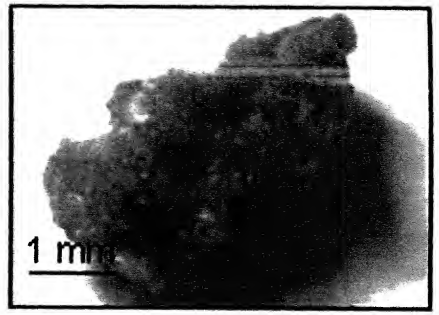
Composite wall width: 2.5 - 5.0 µ

No. of wall groups: 1

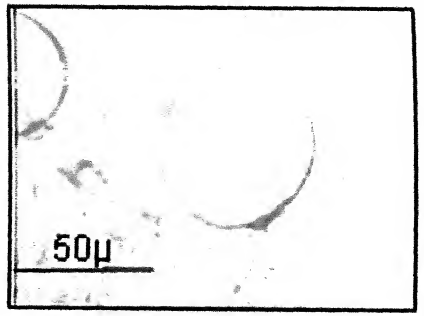
Spores formation within roots: Present

Sporocarp: Present

Colour of sporocarp: Creamish yellow

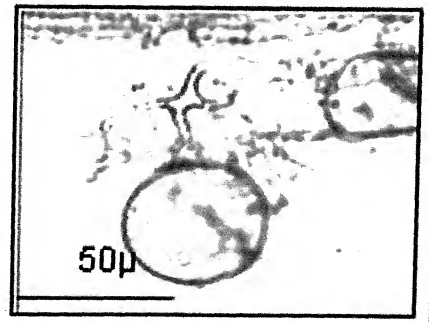


Sporocarp



Spores

Reaction to Meltzer's reagent



Spore in root

Plate 7. Characteristics of *Glomus* 5

Spore colour: Silver shiny

Spore size:

Mean: 54.2 x 54 µ

Range: 48 – 72 x 48 – 67 µ

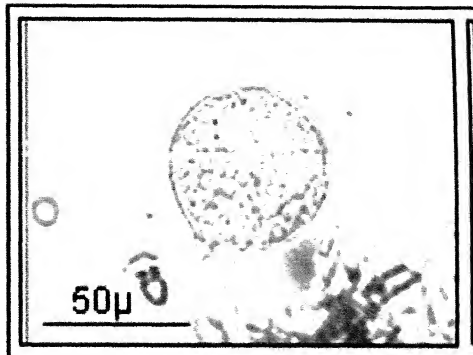
Composite wall width: 2.4 µ

No. of wall groups: 1

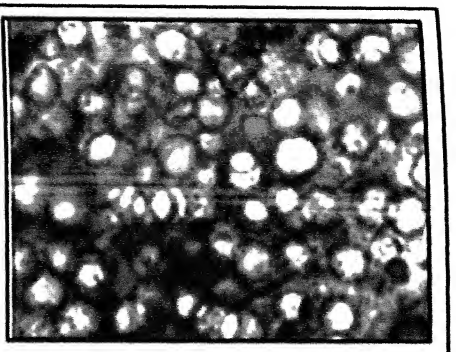
Spores formation within roots: Present

Sporocarp: Present

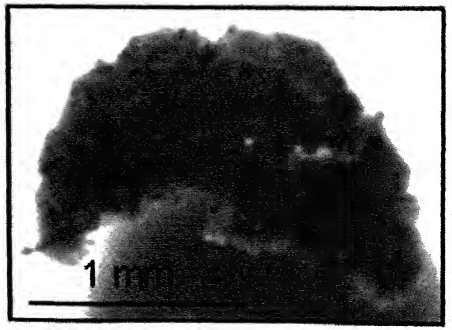
Colour of sporocarp: Creamish yellow



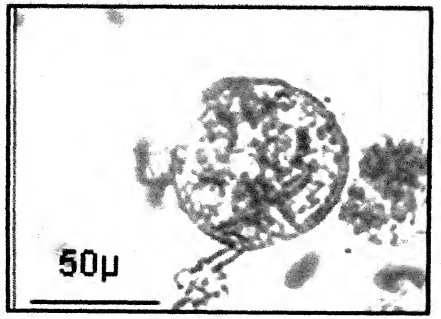
Spores



Spores in sporocarp



Sporocarp



Spore in Meltzer's reagent

Plate 8. Characteristics of *Glomus* 6

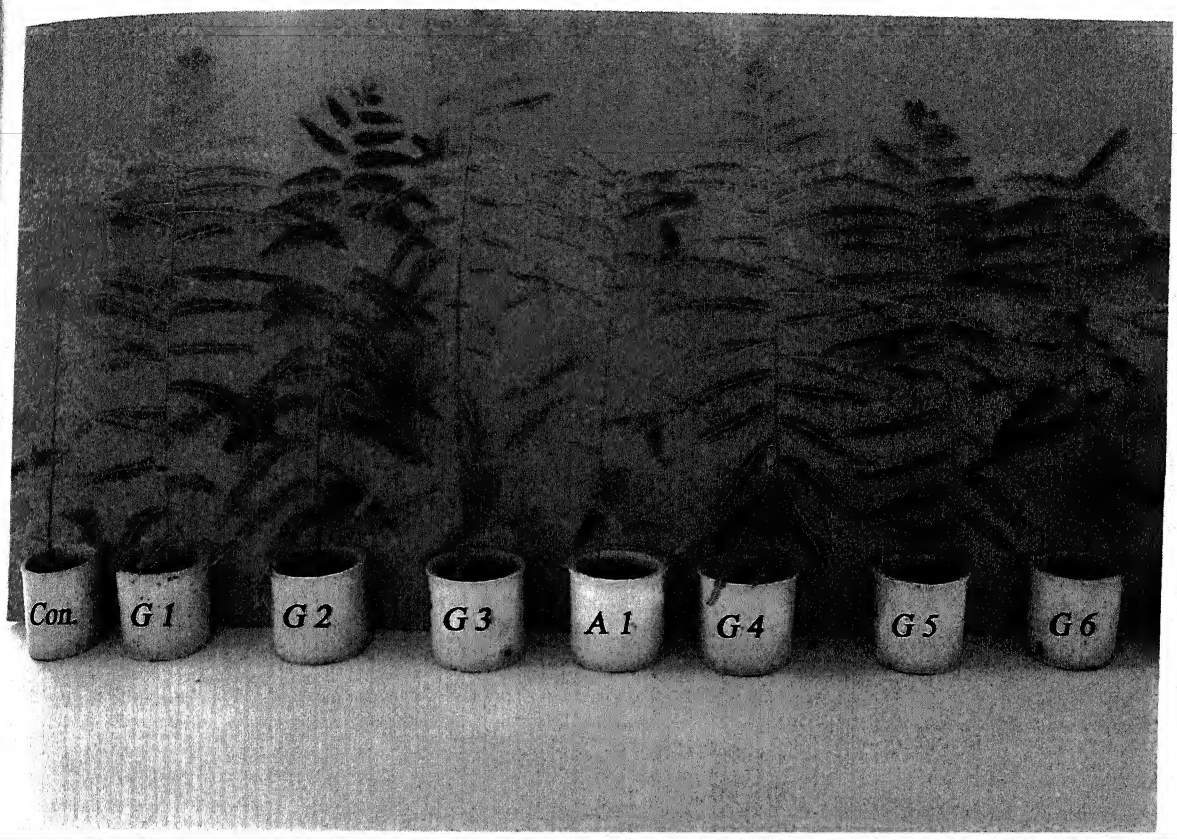


Plate 9. Effect of inoculation of VAM species on growth of Aonla (*Emblica officinalis* Gaertn.) seedlings

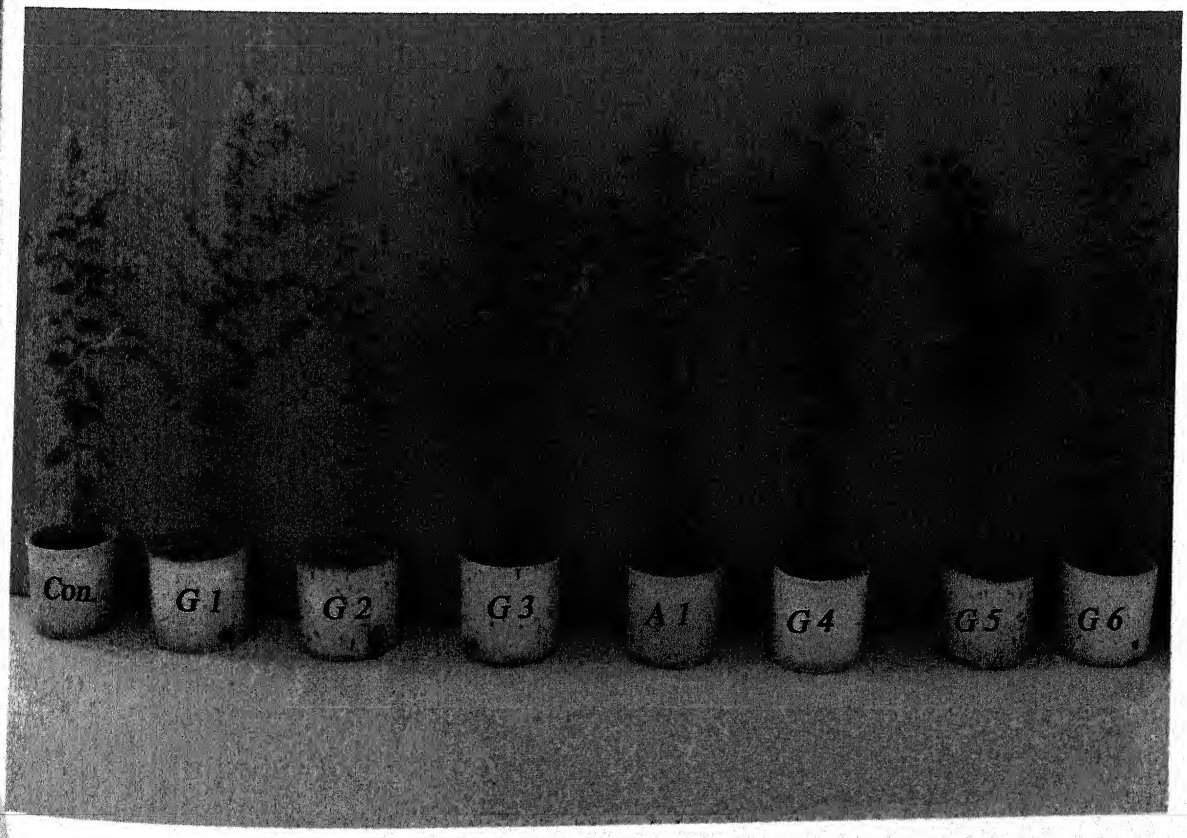


Plate 10. Effect of inoculation of VAM species on growth of Ber (*Zizyphus mauritiana* Lamk.) seedlings

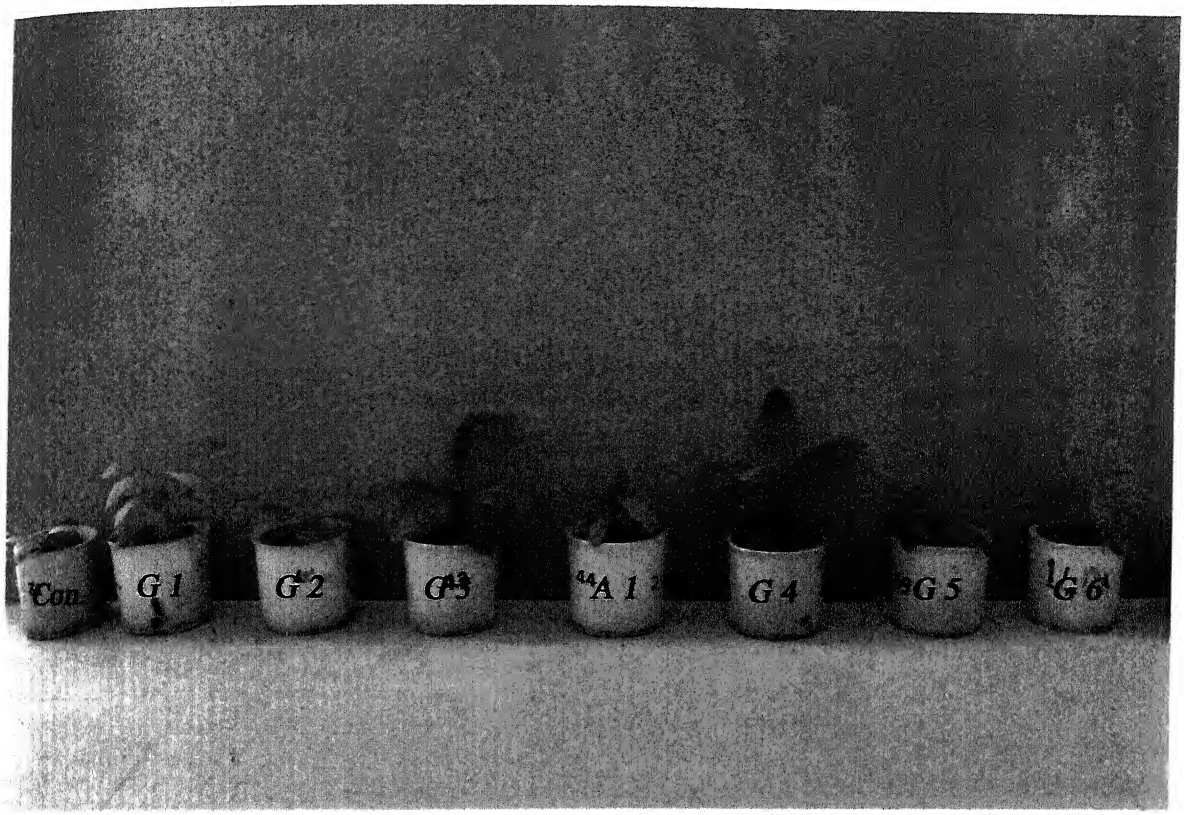


Plate 11. Effect of inoculation of VAM species on growth of Chironji (*Buchanania lanzan* Spr.) seedlings

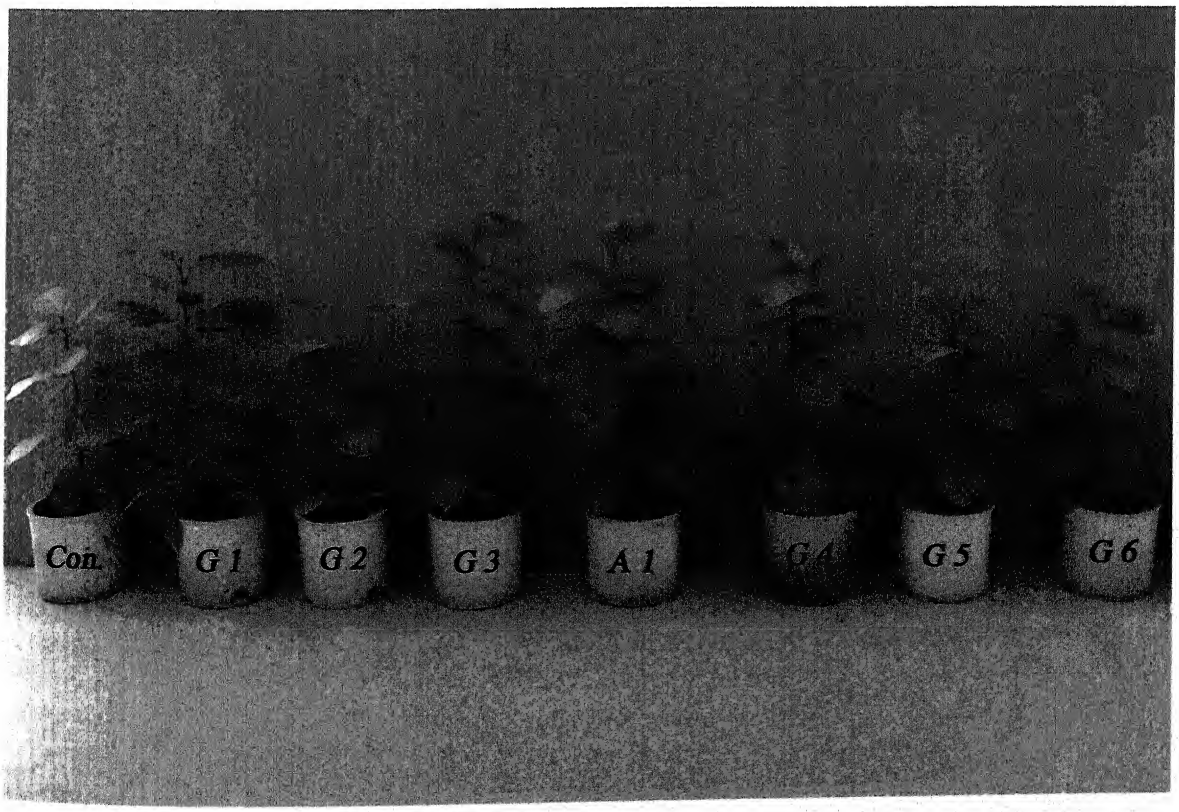


Plate 12. Effect of inoculation of VAM species on growth of Lasoda (*Cordia myxa* Roxb.) seedlings


Discussions

DISCUSSIONS

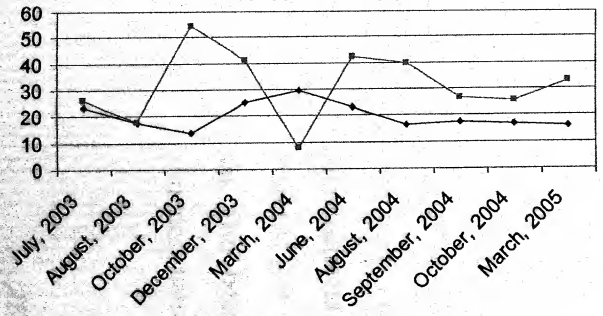
The results obtained from all the experiments conducted in the present study are discussed hereunder in detail with an attempt to through light in field surveys, identification of common VAM fungi in rhizosphere of Aonla, Ber, Chironji and Lasoda, culturing, purification and multiplication of VAM fungi and screening of the fungi for improved seedling growth under nursery conditions.

5.1 Colonization of Aonla, Ber, Chironji and Lasoda Roots By Vesicular Arbuscular Mycorrhizal Fungi: Observations on VAM activity in Aonla were recorded in its four varieties viz., Chakaiya, Kanchan, Krishna and NA-7, on nine sampling dates (Table 4.1). Maximum colonization index was noticed in variety Krishna (22.7%), followed by Kanchan (20.0%), Chakaiya (16.5%) and NA-7 (16.3%). Observations in Krishna were at par with Kanchan and superior to Chakaiya and NA-7. VAM spore count per 100 g soil in rhizosphere of different Aonla varieties were at par, which ranged from 9.2 to 12.9. The data on colonization index in rhizosphere of Ber varieties recorded during different seasons are presented in Table 4.8 and 4.9. Values for colonization index of different Ber varieties (Banarasi Karaka, Gola and Seo), its Desi plants and three wild relatives (Ghot, Jharberi and Makor) did not differ significantly. Whereas, spore count (number per 100 g soil) was maximum in Banarasi Karaka (29.5), followed by Ghot (28.8), Gola (25.8), Jharberi (22.4) and Makor (21.0). Poorest spore counts were recorded in Desi (19.2) and Seo (15.3).

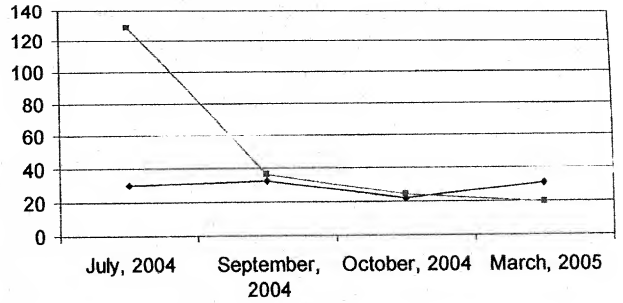
Contrasting reports on susceptibility of varieties of a given plant species to VAM fungi are available in literature. For example, Sieverding (1991) has reported little differences between cassava clones in their susceptibility to VAM fungi in terms of colonization index. Whereas, Devagiri *et al.* (2001) reported seed source dependent variation in mycorrhizal

colonization in *Dalbergia sissoo*. Twenty nine seed sources from India and Nepal were screened to identify good mycorrhizas forming seed sources. Results indicated good amount of variation among different seed sources with respect to VAM colonization index (24 to 54%). Krishna *et al.* (1985) found in their investigation on the horizontal susceptibility of finger millet to VAM fungi that genetic factors responsible for high levels of infection were "dominant" when cultivars of high and low susceptibility were crossed. Optimum infection ratings (not necessarily the highest ratings) are prerequisites for the physiological effectiveness of the symbiosis.

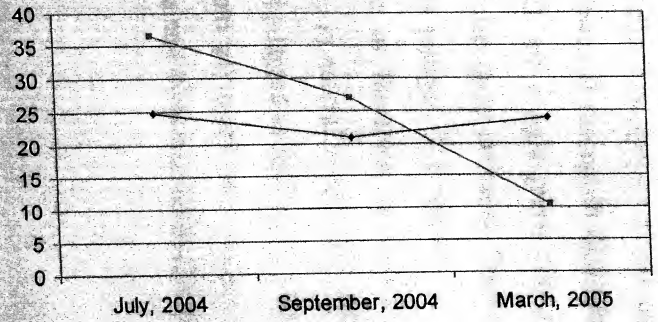
Results on colonization index and spore count in rhizosphere of Chironji and Lasoda are presented in Table 4.10 and 4.12. Differences in colonization index values of both trees were non-significant during different sampling dates. In Chironji, the values were at par at Jakhlon and Nilkanth and in Lasoda, it was maximum in silvi-pasture plot NRCAF (32.9%), followed by block plantation NRCAF (22.4%) and Nareta (16.9%). In both trees, the counts were maximum during July 2004, followed by September 2004, June 2005 and March 2005. In Chironji, spore counts per 100 g soil were at par at two sampling sites. In Lasoda, it was maximum in block plantation NRCAF (20.3) followed by silvi-pasture NRCAF (15.4) and Nareta (2.0). The soils were red textured at all sampling sites except Nareta, where its texture was black. Thus, the VAM activity was more in red soil than black soil in Lasoda and development of the fungi was more during rains as compared to other seasons in both trees. Plots of colonization index and spore population v/s date of samplings in tested tree species exhibited a set pattern. Formation of fresh roots was observed at faster rate when sufficient soil moisture was available in the field, especially during rainy season. Colonization of these newly formed roots took some time. But during this period, increased VAM activity was recorded in terms of increased spore population. After rainy season, rate of fresh root formation declined, soil moisture reduced and major portion of live



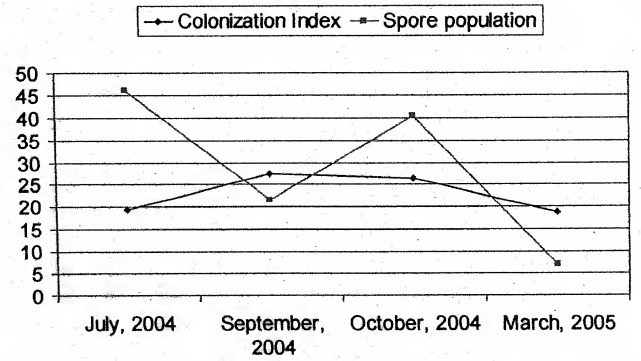
AONLA



BER



CHIRONJI



LASODA

Fig. 5.1 Colonization index and spore population of VAM fungi in Aonla, Ber, Chironji and Lasoda during different months of the year

fine roots became mycorrhizal. But in absence of fresh roots, VAM activity as a whole, declined along with spore population (Fig. 5.1).

In present study, good level of mycorrhization reported for above mentioned tree species by VAM fungi is consistent with information available in literature. VAM fungi have the widest host range and distribution of all the mycorrhizal associations. It is estimated that about 90% of vascular plants normally establish mutualistic relationship with VAM fungi. VAM fungi have been observed in 1000 genera of plants representing some 200 families. According to Gerdemann (1975), it is easier to list most plant families that do not form VAM mycorrhizae than to list those that do. Families not forming VAM mycorrhizae include Pinaceae, Betulaceae, Orchidaceae, Fumariaceae, Commelinaceae, Urticaceae, and Ericaceae. Families that rarely form VAM mycorrhizae include the Brassicaceae, Chenopodiaceae, Polygonaceae, and Cyperaceae.

5.2 <u>Common VAM Species</u>: Three species of *Glomus*, two species of *Acaulospora*, three species of *Gigaspora* and two species of *Scutellospora* were recorded in rhizosphere of Aonla, Ber, Chironji and Lasoda (Fig. 5.2). *Glomus* was most predominant genus, followed by *Acaulospora* and *Gigaspora*. Photographs of some common local VAM species are shown in Plate 1. *Glomus* I was most abundant species in rhizosphere of all tested four tree species, followed by *Glomus* II (except in Ber) where *Acaulospora* I had second rank. *Acaulospora* II and a light green coloured *Gigaspora* species (especially in Aonla) were also quite common. Presence of *Glomus mossae* and some other species was meager. The reported results are in agreement with few reports available in literature on dominance, distribution and establishment of VAM fungi in natural ecosystems. Bhatia *et al.* (1996) have reported that *Glomus* is well adapted to fertile soil with high nutrient levels. It has also been reported from all types of soils in tropical and temperate climates, natural ecosystems and disturbed lands (Mukerji, 1996), through the

species represented within the genus may vary. Genera of *Scutellospora, Acaulospora* and *Gigaspora* are more abundant in soils having low nutrient levels (Koske, 1987). So presence of spores of *Acaulospora, Gigaspora* and *Scutellospora* in rhizosphere of Aonla, Ber, Chironji and Lasoda in good numbers reflects the poor nutritional status of local soils.

5.3 Colonization Index, Spore Count and Species Composition in Aonla Rhizosphere Variety NA-7 With and Without Wheat As An Intercrop:

Data on colonization index and spore count per 100 g soil in Aonla rhizosphere variety NA-7 with and without wheat as an intercrop are presented in Table 4.6. During crop period, colonization index was significantly superior in Aonla plants with wheat (28.4%) than in Aonla plants grown without wheat (20.2%). While during pre- crop and post- crop periods, it was at par in both treatments i.e. with (22.5%, 23.7%) and without wheat (25.6%, 24.3%). The observed differences can be explained on the basis of better moisture availability in agroforestry plot, as the intercrop was irrigated. The observations on VAM spore count per 100 g soil from rhizosphere of Aonla plants grown with wheat were at par with respective observations on Aonla plants grown without wheat, during all above mentioned crop periods. VAM species composition did not show any qualitative changes in these observations, however quantitative changes were recorded. Thus, the results showed that wheat as an inter-crop increased VAM activity in Aonla rhizosphere during crop period. Kumar *et al.* (2007) have reported that VAM colonization index of eucalyptus roots was significantly more in agroforestry plots (29.7%) than in pure plantation (13.7%). Further, it has been reported that in Siris (*Albizia procera* (Roxb.) Benth.) based agroforestry systems intercropping increased the inoculum potential of VAM fungi in tree rhizosphere.

Fallow has been reported by many workers to reduce soil population of VAM fungi (Barbara and Hetrick, 1984). Therefore, more extensive green

Table 5.1 VAM species composition in rhizosphere of selection minor fruit crops

VAM species	Number* of spores in				Total
	Aonla	Ber	Chironji	Lasoda	
Glomus I	617	946	43	60	1666
Glomus II	245	146	17	35	443
Glomus mosseae	0	0	1	0	1
Acaulospora I	127	246	2	16	391
Acaulospora II	91	78	0	1	170
Gigaspora sp.	56	32	0	0	88
Scutellospora I	0	0	1	0	1
Scutellospora II	0	0	0	1	1
Total	1136	1448	64	113	2761

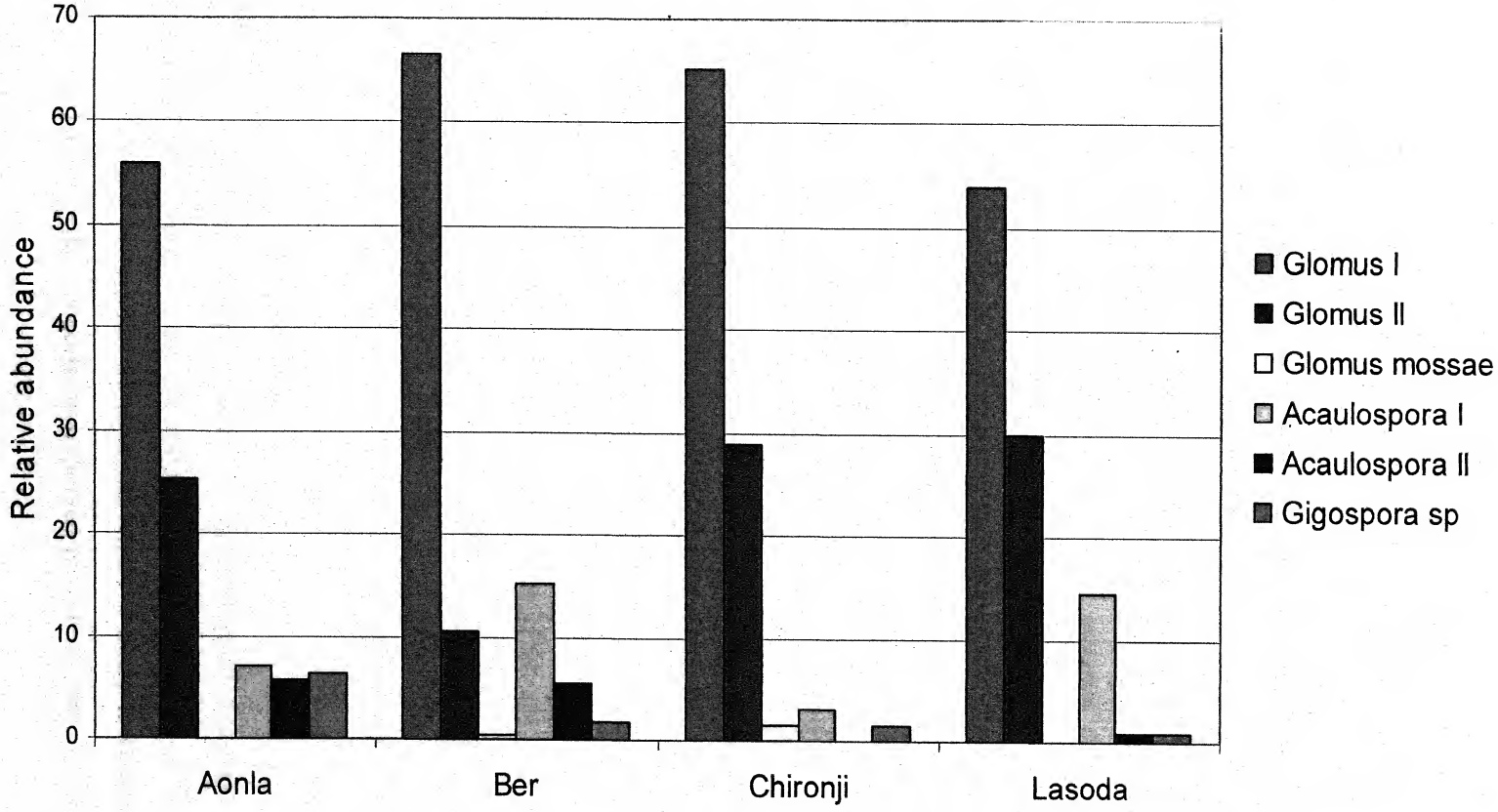


Fig. 5.2 Relative abundance of VAM species in rhizosphere of some selected minor fruit trees

cover and biological diversity in agroforestry systems as compared to pure block plantation may enrich the VAM-mycorrhizal flora of soil. Though, VAM fungi are obligate symbionts but these are non specific in their selection of host (Bonfante and Fasolo, 1987). These have been reported to have at least 300,000 receptive hosts, representing 200 families. Some individual VAM fungi may have access to thousand of hosts (Kendrick and Berch, 1985). Thus, possibility of cross infectivity among tree and crop components of a given agroforestry systems exist, which is likely to improve soil VAM-mycorrhizal microflora. Reid and Bowen (1979) have reported that maximum VAM colonization of *Medicago* plants occurred at field capacity and it reduced under conditions which were either too wet or too dry. Thus, the improved moisture conditions of agroforestry systems with irrigated inter-crops like wheat may increase the population of VAM fungi in soil compared to dry soils of pure plantation. Sieverding (1991) has reported that small phosphate applications generally may improve VAM fungal activities on infertile soils and their population benefits from N application probably due to longer maintenance of photosynthetic leaf area. In selected experimental fields in present study, the fertilizers were applied to intercrops not to tree. So tree component must be receiving these at sub optimal level, which might have improved the VAM flora under tree canopy. Thus the observed increase in VAM population due to intercropping can be due to following possible reasons:

1. Presence of more extensive green cover in agroforestry systems
2. Better moisture and nutrient availability
3. Improved soil conditions
4. Cross infection of trees and crops in agroforestry systems by VAM fungi

In conclusion, it can be stated that inter-cropping increases activity of VAM fungi in agroforestry systems, which is likely to confer many benefits on the host. Many reports on improved growth of trees, which may be partly

due to VAM fungi, in agroforestry systems than in pure plantations are available (Chaturvedi and Pandey, 2000; Mathur and Sharma, 1983).

5.4 VAM Activity in Rhizosphere of Upland and Low Land Aonla Plants:

Data on colonization index and spore count of VAM fungi in rhizosphere of Aonla (variety Krishna) under water-logged (lowland) and normal conditions (upland), recorded from July 2003 to October 2004 are presented in Table 4.4. Mean colonization index was significantly superior in upland plants (22.7%) as compared to water logged plants (13.6%). Similar trend was recorded for VAM spore count per 100 g soil in upland (11.6) and lowland plants (7.3). The index and spore count were significantly more in upland plants than lowland plants during July 2003 and August 2003. Normal rains were received during this period (Appendix I). In October 2003 rains stopped, the index value in lowland plants increased during this month and was at par with respective value in upland plants, but spore count remained significantly more in upland plants. The weather remained more or less dry from October 2003 to May 2004. Index value in upland (more porous red soil) recorded sharper increase than in lowland plants (black soil) up to March 2004 and the spore count declined in both treatments during this dry period. With the start of rains during June 2004 both index and spore count showed sharper increase in upland plants as compared to lowland plants. But the monsoon declined early in August 2004. The index remained significantly superior in upland plants during August 2004 and September 2004, but the spore count declined in both treatments. As indicated earlier, formation of fresh roots in the trees was observed at faster rate when sufficient soil moisture was available in the field, specially during rainy season. Colonization of these newly formed roots took some time. But during this period, increased VAM activity was recorded in terms of increased spore population. After rainy season, rate of fresh root formation declined, soil moisture reduced and major portion of live roots became mycorrhizal. But in absence of fresh roots, VAM activity as a whole,

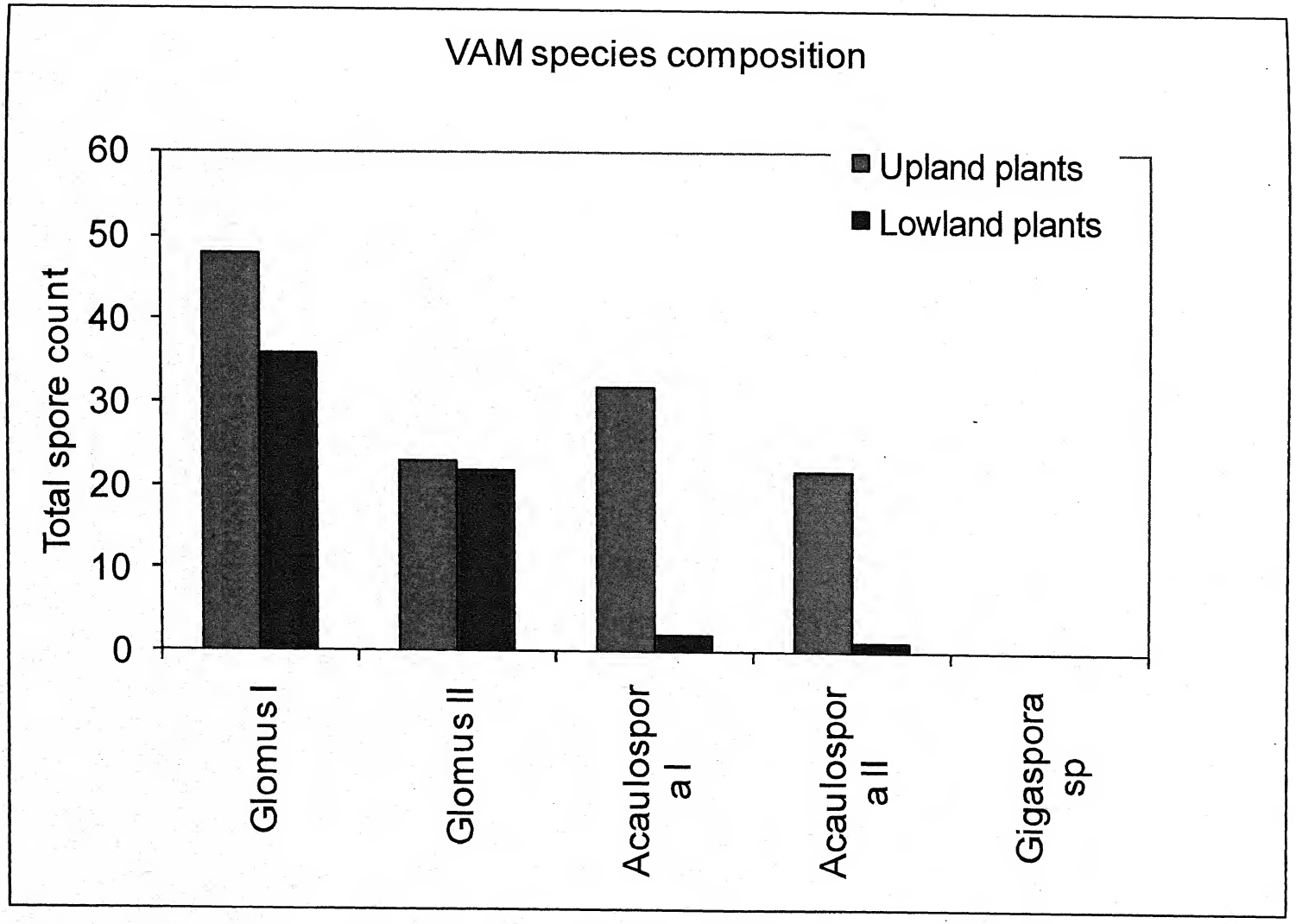


Fig. 5.3 VAM Species composition in rhizosphere of upland and lowland of Aonla variety krishna

declined along with spore population. In upland plants four VAM species were recorded viz. *Glomus* I, *Glomus* II, *Acaulospora* I and *Acaulospora* II. In lowland plants, only *Glomus* species were observed. Similar trends in mycorrhization of upland and lowland plants were recorded in Aonla (Kumar and Bisaria, 1999) and Hardwickia plantations (Kumar and Bisaria, 2000) during rainy season in 1997 and 1999, respectively.

Thus, the results clearly showed that VAM activity in terms of colonization index, spore count and mycorrhizal diversity were more in rhizosphere of upland plants than lowland plants and *Glomus* species had better adaptability to water logged conditions. This increase could be due to submerging of roots during rainy season and heavy soil texture in low lying part of the field. Reid and Bowen (1979) have reported that VAM activity is reduced under conditions which are either too wet or too dry. They found that maximum VAM colonization occurred at –0.2 bar water potential. VAM colonization dropped with each further decrease in water potential. VAM colonization was reduced to 50% of the maximum when the soil was saturated. Redhead (1975) has also reported similar results in that VAM spore production was excellent when *Khaya* plants were watered daily in sand cultures. Weekly watering reduced spore germination by 90% and watering twice per day (water logging) reduced spore production by 75%. Under water saturation condition, O_2 diffusion is limited and anaerobiosis may develop which can result in the release of toxic compounds such as Mn, H_2S, and various organic acids. Reduced 0_2 concentrations can severely inhibit VAM spore germination and root colonization (Mosse *et al.* 1981; Saif 1981).

5.5 <u>Effect of Soil Type on VAM Activity</u>: Results on effect of different soil types on colonization index of Aonla, soil moisture, soil surface temperature and soil temperature at 10 cm depth during summer months are shown in Table 4.14. Maximum colonization was recorded in lateritic soil (27.9%), which was significantly more than colonization in red (21.2%) and black soils

(17.9%). The index significantly increased from March 2005 (21.9%) to April 2005 (27.4%), significantly reduced from April 2005 to May 2005 (19.3%) and the observations during May 2005 and June 2005 (22.0%) were at par. In black soil, observations on colonization index during different months remained at par. In lateritic soil, the index values, significantly increased from March 2005 to April 2005 then significantly decreased from April 2005 to May 2005 and were at par during May 2005 and June 2005. The trend in red soil was similar to lateritic soil except that the value was significantly more during June 2005 than May 2005 value. Maximum soil moisture was recorded during June 2005 (6.4%), followed by April 2005 (4.7%) and May 2005 (3.6%). High values of soil moisture during June 2005 were due to rains just before sampling date. Among different soil types, maximum percent soil moisture was recorded in black soil (5.7%), followed by lateritic soil (4.8%) and red soil (4.2%). Maximum soil temperature at 10 cm depth was recorded during May 2005 (46.3^0C), followed by June 2005 (44.3^0C) and April 2005 (36.4^0C). Differences in sub-soil temperatures were non-significant in different soil types. Maximum soil surface temperature was recorded during May 2005 (71.4^0C), followed by June 2005 (59.4^0C) and April 2005 (46.4^0C). Among three soil types, maximum surface temperature was recorded in black soil (61.7^0C), followed by lateritic soil (59.0^0C) and red soil (56.5^0C). Thus, the results showed that maximum VAM activity was present in lateritic soil, followed by red soil and black soil. Results also showed that maximum percent soil moisture and soil surface temperatures were recorded in black soil, followed by lateritic soil and red soil. Soil surface temperature did not effect the sub soil temperatures in the root zone and the temperature at 10 cm depth was not significantly different in studied soil types. Though, VAM development in the roots is directly related to soil moisture below saturation point (Reid and Bowen, 1979), yet the slightly higher amount of soil moisture available in black soil was found insufficient to raise the VAM activity to levels, recorded in other soil types. Better VAM fungi activity recorded in

lateritic soil than other soil types can be due to better aeration. Reduced O_2 concentration has been reported to inhibit VAM spore germination and root colonization (Mosse *et al.*, 1981; Saif, 1981).

5.6 Effect of Different VAM Inoculations on Growth of Selected Minor Fruit Trees:

5.6.1 Aonla: Results on effect of inoculation of different VAM species on growth and P uptake of Aonla (*Emblica officinalis* Gaertn.) seedlings are presented in Table 4.20 and Fig. 4.7. Shoot length was significantly increased by *Glomus* 1 and *Glomus* 4. Collar diameter was significantly increased by *Glomus* 1. *Glomus* 1, *Glomus* 6, *Glomus* 4 and Glomus 3 significantly increased fresh shoot weight, *Glomus* 1, *Glomus* 4, *Acaulospora* 1, *Glomus* 3 and *Glomus* 6 significantly increased dry shoot weight and *Glomus* 1, *Glomus* 6, *Acaulospora* 1, and *Glomus* 3 significantly increased dry root weight. Maximum phosphorus uptake per plant was recorded in *Glomus* 3 (97.197 mg), followed by *Acaulospora* 1 (72.383 mg) and *Glomus* 6 (57.977 mg), which were significantly superior to control. *Glomus* 1 was ranked as most efficient VAM fungi for Aonla, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by *Acaulospora* 1 and *Glomus* 3 (Table 5.2).

5.6.2 Ber: Results on effect of inoculation of different VAM species on growth and P uptake of Ber (*Zizyphus mauritiana* Lamk.) seedlings are presented in Table 4.21 and Fig. 4.8. None of tested AM fungi increased shoot length and collar diameter of Ber. *Glomus* 1 (48.07 g) and *Glomus* 6 (38.78 g) significantly increased shoot fresh weight. *Glomus* 3 (62.42 g), *Glomus* 4 (59.43 g) and *Glomus* 6 (57.90 g) significantly increased root fresh weight. *Glomus* 1 significantly increased dry shoot weight and *Glomus* 3, *Glomus* 6, *Glomus* 4 (22.37 g) and *Glomus* 1 significantly increased dry root weight. Maximum phosphorus uptake per plant was recorded in *Glomus* 3 (75.897 mg) followed by *Glomus* 1 (68.507 mg) and *Glomus* 6 (64.537 mg), which were significantly superior to control. *Glomus* 3, *Glomus* 6 and *Glomus* 1 were

found superior to other VAM fungi in enhancing seedling dry biomass and P uptake by Ber seedlings (Table 5.2).

5.6.3 Chironji: Results on effect of inoculation of different VAM species on growth and P uptake of Chironji (*Buchanania lanzan* Spr.) seedlings are presented in Table 4.22 and Fig. 4.9. At harvest, shoot length of Chironji seedlings was significantly more in *Glomus* 4 (23.2 cm), *Glomus* 6 (19.8 cm), *Glomus* 1 (18.5 cm), *Glomus* 3 (16.7 cm) and *Glomus* 5 (13.5 cm) than control (10.3 cm). Significantly superior collar diameter was recorded in *Glomus* 4 (7.5 mm), *Glomus* 6 (7.0 mm), *Glomus* 1 (6.4 mm), *Acaulospora* 1 (5.5 mm), *Glomus* 5 (5.3 mm) and *Glomus* 3 (5.2 mm) as compared to control (3.9 mm). *Glomus* 6 (21.0 g), *Glomus* 4 (20.6 g), *Glomus* 1 (14.7 g) and *Glomus* 3 (10.0 g) significantly increased fresh shoot weight and *Glomus* 4 (23.8 g), *Glomus* 6 (21.0 g), *Glomus* 1 (17.8 g) and *Glomus* 3 (14.9 g) significantly increased fresh root weight. *Glomus* 4 (7.7 g) *Glomus* 6 (7.1 g), *Glomus* 1 (5.0 g) and *Glomus* 3 (4.0 g) significantly increased dry shoot weight. *Glomus* 4 (8.6 g), *Glomus* 6 (7.1 g), *Glomus* 3 (4.8 g) and Glomus 1 (4.6 g) significantly increased fresh shoot weight. Maximum phosphorus uptake per plant was recorded in *Glomus* 6 (22.487 mg) followed by *Glomus* 1 (15.733 mg), *Acaulospora* 1 (15.570 mg) and *Glomus* 4 (12.857 mg), which were significantly superior to control. *Glomus* 6 was ranked as most efficient VAM fungi for Chironji, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by *Glomus 4* and *Glomus* 1 (Table 5.2).

5.6.4 Lasoda: Results on effect of inoculation of different VAM species on growth and P uptake of Lasoda (*Cordia myxa* Roxb.) seedlings are presented in Table 4.23 and Fig. 4.10. Shoot length was significantly increased by *Glomus* 4 (60.2 cm) and *Glomus* 5 (57.8 cm). None of tested VAM fungi increased collar diameter of Lasoda. *Glomus* 4 (64.4 g), *Glomus* 5 (62.8 g) and *Glomus* 1 (58.6 g) significantly increased fresh shoot weight and *Glomus* 2 (106.1 g) and *Glomus* 4 (100.1 g) significantly increased fresh root weight.

Table 5.2 Rank analysis of VAM fungi for their efficiency based on dry biomass and P uptake by selected minor fruit trees.

Plant growth parameters	Rank of cultures						
	Acaulospora 1	*Glomus* 1	Glomus *2*	*Glomus* 3	*Glomus* 4	*Glomus* 5	*Glomus* 6
Aonla							
P uptake per plant	2	5	7	1	4	6	3
Shoot dry weight	3	1	7	4	2	6	5
Root dry weight	3	1	7	4	5	6	2
Total	8	7	21	9	11	18	10
Rank	II	I	VII	III	V	VI	IV
Ber							
P uptake per plant	4	2	7	1	5	6	3
Shoot dry weight	6	1	7	3	4	5	2
Root dry weight	6	4	7	1	3	5	2
Total	16	7	21	5	12	16	7
Rank	IV	II	V	I	III	IV	II
Chironji							
P uptake per plant	3	2	6	5	4	7	1
Shoot dry weight	5	3	7	4	1	6	2
Root dry weight	5	4	6	3	1	7	2
Total	13	9	19	12	6	20	5
Rank	V	III	VI	IV	II	VII	I
Lasoda							
P uptake per plant	6	1	2	3	5	4	7
Shoot dry weight	7	3	5	6	1	2	4
Root dry weight	7	4	1	2	3	5	6
Total	20	8	8	11	9	11	17
Rank	V	I	I	III	II	III	IV

None of tested VAM fungi increased dry shoot weight and *Glomus* 2 (106.1 g) and *Glomus* 4 (100.1 g) significantly increased fresh root weight. *Glomus* 1 (110.767 mg), *Glomus* 2 (86.423 mg), *Glomus* 3 (84.143 mg), *Glomus* 5 (82.943 mg), *Glomus* 4 (80.703 mg), *Acaulospora* 1 (80.557 mg) and *Glomus* 6 (78.737) significantly increased P uptake. *Glomus* 1 was ranked as most efficient VAM fungi for Lasoda, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by *Glomus* 2 and *Glomus* 4 (Table 5.2).

Species and strains of VAM fungi have been shown to differ in the extent to which they increase nutrient uptake and plant growth (Abbott *et al.,* 1978; Carling *et al.,* 1980; Daniels *et al.,* 1981; Mosse, 1972; Nemec *et al.,* 1978; Powell, *et al.,* 1980 and Sanders *et al.,* 1977). These observations have led to a discussion of efficient or superior strains of mycorrhizal fungi (Powell *et al.,* 1976). Such terminology has often been used with the implication that any given species may have some kind of "innate effectiveness". There are at least four factors which are related to effectiveness of VAM fungi:

1. The ability to form extensive and well distributed hyphae in soil
2. The ability to form extensive infections throughout the developing root system
3. The ability of hyphae to absorb phosphorus from the soil solution
4. The longevity of the transport mechanism along hyphae and into the root (Abbott *et al.*, 1982).

These characteristics are all involved with the uptake and transport of nutrients and they may differ for different species or strains of fungi. The only one of these four characteristics which has so far been shown to differ among species of VAM fungi is the ability to infect roots. There have been no reports which compare VAM fungi for their ability to form hyphae in soil, absorb phosphorus from the soil solution, or transport phosphorus along hyphae and into the root. The fungi may indeed differ in any of these three attributes.

However, currently we only have data to show that they differ in their ability to infect roots rapidly and/ or extensively.

Where the development of infection has been studied with time in relation to plant growth, those species which were effective at increasing plant growth were the ones which resulted in the most rapid and extensive infection of roots (Sanders *et al.,* 1977). The rate at which different fungal species reach their plateau infection level will depend upon the number of infective propagules and their ability to spread within soil or along and within roots by secondary infections (Daniels *et al.,* 1981; Powell *et al.*, 1981 and Smith *et al.*, 1981). The effectiveness of a particular species of VAM fungus will also be related to its ability to infect roots of the host at a time most appropriate for increased uptake of a nutrient which is deficient for plant growth.

Frequently, at a final harvest, there is no difference in the percentage of roots infected by different species of fungi although they may have produced differences in plant growth (Owusu *et al.,* 1979). This could arise if fungi differed in the rate at which they formed mycorrhizae (Abbot *et al.,* 1978).

Species of VAM fungi may indeed differ in their ability to from hyphae in soil, (Bevege *et al.,* 1975), both in the distribution and quantity of hyphae. It has already been shown that the development of infection is correlated with the ability of a fungus to increased plant growth (Abbott *et al.,* 1981). However, we do not know whether the growth of external hyphae is a characteristics which is independent of the development of infection with in roots. Do species of VAM fungi have a constant and "innate" ability to take up nutrient and increased plant growth which is independent of the ability of the fungus to infect the host? So far there is no evidence to suggest this. More research is needed to define the characteristics which make fungi efficient at enhancing plant growth. Clearly, there is scope for selecting fungi for field inoculation which are more efficient at increasing plant growth than those already residents in many soils. To be successful however, they must also have characteristics which enable them to persist after inoculation (Abbott and

Table 5.3 List of efficient vesicular arbuscular mycorrhizal (VAM) fungi for different agricultural plant species

Plant Species	Efficient mycorrhizal fungus/fungi	Mycorrhizal fungi tested	Parameters evaluated	References
Agriculture crops				
Allium cepa (Onion)	*Gigaspora margarita*	*G. margarita*, *G. calospora*, and a known AM fungus	Leaf number, dry matter, P-uptake, bulb yield	Ramana and Babu (1999)
	G. calospora	*G. margarita*, *G. calospora*, and a known AM fungus	Root colonization	Ramana and Babu (1999)
Amorphophallus paeonufolius	*Glomus mosseae* + *G. aggregatum*	*G. mosseae*, *G. aggregatum*, *Gigaspora albida*, *Pisolithus tinctorius*	Tuber yield / plant	Ganesan and Mahadevan (1994)
Ananas comosus	*Glomus fasciculatum*	*G. fasciculatum*, *Glomus sp.*, *Acaulospora sp.*, *Scutellospora sp*	Plant growth, nutrition	Jaizme-Vega and Azcon (1995)
Acacia nilotica	*Glomous mosseae* + *Gigaspora gilmorei*	*G. mosseae*, *G. constrictum*, *Gigaspora gilmorei*, and their combinations	Collar diameter, root –shoot dry weight and length	Mandal and Kaushik (1994)
Acacia auriculaeformis	*Glomus etunicatum*, *G. macrocarpum*	*G. etunicatum*, *G. macrocarpum*, *G. fasciculatum*, *G. mosseae*	Height, diameter, biomass, P-uptake	Aggangan, Lorilla, and Cruz (1990)
Acer saccharum (Sugar maple)	*Glomus macrocarpum*	*G. macrocarpum*, *G. clarum*, *G. epigaeum*, *G. mosseae*	Leaf number, mean lateral root number	Reid, Parker, Mitchell et al. (1988)
Azadirachta indica (neem)	*Glomus mosseae*	*Glomus mosseae*, *G. fasciculatum*, and seven other VAM fungi	Plant height, stem girth, biomass, P-content, zinc concentration, root colonizations	Sumana and Bagyaraj (1999)

Cajanus cajan	*Glomus clarum*	*G. fasciculatum* and seven other VAM fungi	Plant growth	Diederichs (1992)
	Glomus etunicatum	*G. etunicatum, Gigaspora margarita*	Shoot dry matter, nutrient uptake	Ahiabor and Hirata (1994)
Capsicum	*Glomus intraradices*	*G. intraradices,* indigenous mixed culture, commercial inoculum (Mycorise & C)	Fruit yield	Gaur, Adholeya, and Mukerji (1998)
Carica papaya	*Glomus fasciculatum*	*G. fasciculatum, Glomus sp., Acaulospora sp., Scutellospora sp.*	Plant growth, nutrition	Jaizme-vega and Azcon (1995)
Cacocasia esculenta	*Glomus mosseae*+ *G. aggregatum*	*G. mosseae, G. aggregatum, Gigaspora albida, Pisolithus tinctorius*	Tuber yield / plant	Ganesan and Mahadevan (1994)
Cucumis sativus	*Glomus caledonium*	*G. caledonium, Glomus sp.*	P-uptake	Joner and Jokobsen (1994)
Eleusine coracana	*Glomus caledonicum*	*G. caledonicum, G. mosseae, G. fasciculatum, G. epigaeum (G. versiforme), Gigaspora calospora*, G. margarita	Mycorrhizal efficacy, root colonization	Tewari, Johri, and Tandon (1993)
Fragaria xananassa (micropropagated)	*Glomus versiforme* 36-366	*G. versiforme* (2 isolates), *G. mosseae, G. etunicatum*	Yield, production of runners	Taube-Baab and Baltruschat (1996)
Glycine max	*Acaulsopora scrobiculata*	*A. scrobiculata, Glomus intraradices,* and four other AM fungi	Plant growth, crop yield	Vasuvat, Nopamornbodi, and Thamsurakul (1987)
Lycopersicum esculentum	*Glomus etunicatum*	*Glomus etunicatum, G. mosseae*	Shoot dry weight, plant height	McGraw and Schenck (1981)

cv. Manapal	*G. mosseae*	*Glomus etunicatum, G. mosseae*	Root colonization	McGraw and Schenck (1981)
cv. Walter	*G. mosseae*	*Glomus etunicatum, G. mosseae*	Shoot weight, plant height	McGraw and Schenck (1981)
Manihot esculenta (cassava)	*G. fasciculatum*	*G. fasciculatum*, G. *mosseae*, G. *constrictum, Glomus etunicatum Acaulsopora morrowea*	Root colonization, plant weight, shoot and root dry weight	Sivaprasad, Sulochana and Nair (1990)
Manihot esculenta (cassava)	*G. mosseae* + *G.aggregatum*	*G. mosseae, G.aggregatum, Gigaspora albida, Pisolithus tinctorius*	Tuber yield/ plant	Ganesan and Mahadevan (1994)
Medicago sativa	*Glomus intraradices*	*G. intraradices, G. mosseae, Gigaspora margarita*	Root colonization, fungal sporulation	Douds, Galvez, Becard *et al.* (1998)
Musa acuminata	*Glomus fasciculatum*	*G. fasciculatum, Glomus sp., Acaulospora sp., Scutellospora sp.*	Plant growth, nutrition	Jaisme-Vega and Azcon (1995)
Oryza sativa cv. Prakash	*Glomus intraradices*	*G. intraradices, G. fasciculatum*	Grain yield	Secilia and Bagyaraj (1994)
Orzya sativa (upland rice)	*Acaulospora spinosa*	*Acaulospora spinosa, A. scrobiculata*	Plant biomass, grain yield, root colonization	Ammani and Rao (1996)
Persea Americana	*Glomus fasciculatum*	*G. fasciculatum, Glomus sp., Acaulospora sp., Scutellospora sp.*	Plant growth, nutrition	Jaizme-vega and Azcon (1995)
Polianthes tuberosa (rajnigandha)	*Glomus intraradices*	*G. intraradices*, indigenous mixed cultures, commercial inoculum (Mycorise)	Fruit yield, spike length	Gaur, Adholeya, and mukerji (1998)
Trifolium (Clover)	*Acaulospora trappei*	*A. trappei, A. laevis, Acaulospora sp.,*	Root colonization	Gazey, Abbott, and Robson (1992)

Triticum aestivum wheat (var. Swift)	*Glomus intraradices*	*G. intraradices, Gigaspora margarita*	Plant yield, number of grains/spike	Asif Khan, Khan *et al* (1995)
Vigna mungo (black gram)	*Glomus epigaeum* (*G. versiforme*)	*G. epigaeum, Acaulospora spinosa, A. morrowae*	Root colonization, shoot dry weight, N and P. concentrations	Rao and Rao (1996)
Vigna radiata (green gram)	*Glomus epigaeum (G. versiforme)*	*G. epigaeum, Acaulospora spinosa, A. morrowae*	Root colonization, shoot dry weight, N and P concentrations	Rao and Rao (1996)
Vigna unguiculata	*G. etunicatum*	*G. etunicatum, Gigaspora margarita*	Shoot dry matter, nutrient uptake	Ahiabor and Hirata (1994)
Vigna unguiculata cv. Katumanu K80	*G. etunicatum*	*Glomus etunicatum, G. claroideum, Glomus sp.*	Top dry weight	Obura, Skipper, and Wagner (1987)
Vigna unguiculata cv. California No. 5 black eye	*G. claroideum*	*Glomus etunicatum, G. claroideum, Glomus sp.*	Top dry weight	Obura, Skipper, and Wanger (1987)
Zea mays (pioneer 3905)	*Glomus etunicatum*	*G. etunicatum, G. mosseae, G. aggregatum, G. versiforme*	Leaf mass, protein concentrations	Boucher, Dalpe and Charest (1999)
Nephrolepis exaltata var. whitmanii (fern) micropropagated plants	*Glomus intraradices, G. clarum*	*G. intraradices, G. clarum, G. versiculiferum, G. versiforme*	Root infection	Ponton, Piche, Parent *et al.* (1990)
Tree Crops				
Malus domestica (apple)	*Glomus mosseae*	*G. mosseae, G. macrocarpum*	Root colonization, plant height, plant growth	Miller, Bodmer, and Schuepp (1989)
Hevea brasiliensis	*Glomus clarum, Glomus sp.*	*G. clarum, Glomus sp., A. spinosa, Gigaspora margarita, Entrophospora colombiana, Glomus sp.*, and three other species	Dry weight	Ikram, Mahmud, and Othman (1993)
Tectona grandis	*Glomus leptotichus*	Not mentioned	Seedling growth parameters	Rajan, Reddy, and Bagyaraj (2000)

Zizyphus mauritiana	*Glomus fasciculatum*	*G. fasciculatum, G. mosseae, Scutellospora calospora*	Growth, root colonization, nutrient uptake	Mathur and Vyas (1996)
Citrus jambhiri (rough lemon)	*Glomus fasciculatum*	*G. fasciculatum, G. mosseae, G. etunicatum*	Plant height, top weight, root weight, chlamydospores in soil	Nemec (1979)
Persea American (avocado)	*Glomus fasciculatum*	*Glomus fasciculatum, Acaulospora sp., Scutellospora sp.*	Plantlet growth and nutrition	Jaizme-vega and Azcon (1995)

Robson, 1982). A detailed list of efficient VAM fungi reported to be associated with different agricultural other plant species is given in Table 5.3.

5.7 Build up of Colonization by VAM Fungi of Different Crops in Different Seasons: Results on build up of colonization by VAM fungi of different crops in different seasons (rabi, zaid and kharif) showed that maize was the best host for isolated *Acaulospora* and *Glomus* species among tested crops(Table 4.31 – 4.37).

Choosing the host plant on which to produce VAM inoculation is often difficult. The plants should be well adapted to the conditions under which it must be grown, be an acceptable host for the VAM species which will be produced (Daft *et al.*, 1974 and Reeves *et al.*, 1979), grow rapidly and produce an abundance of roots, and have no pathogens in common with the host for which the VAM inoculum is ultimately intended. Since most plants are mycorrhizal with VAM fungi, a wide variety of plants are available for use in inoculum production. Some hosts which have been used include *Nardus stricta, Coprosoma robusta, Citrus, Sorghum, Stylosanthes, Coleus, onion, pepper, strawberry, barley, corn, peanut, cotton* and *asparagus*. Bagyaraj and Manjunath (1980) screened eight grasses for suitability for mass production of VAM inoculum and Guinea grass (*Panicum maximum* Jacq.) was found to be superior to other species tested, including *Sorghum.* Ferguson (1981) examined a variety of host plants for their suitability in producing VAM inoculum. This work indicated that both peanut and alfalfa were superior to *Sorghum* in producing VAM spores.

Summary

SUMMARY

The present study was carried out to identify suitable VAM species for inoculation of Aonla, Ber, Chironji and Lasoda. To achieve this, experiments on field surveys, identification of common VAM fungi in rhizosphere of above mentioned tree species, culturing, purification and multiplication of VAM fungi and screening of the fungi for improved seedling growth were conducted. The results obtained from various experiments are summarized below:

Among tested varieties of Aonla, maximum colonization index was recorded in Krishna (22.7%), followed by Kanchan (20.0%), Chakaiya (16.5%) and NA-7 (16.3%). Observations in Krishna were at par with Kanchan and superior to Chakaiya and NA-7. Spore counts per 100 gm soil in rhizosphere of different varieties were at par, which ranged from 10.8 to 12.9. Five VAM species belonging to three genera namely, *Glomus, Acaulospora* and *Gigaspora,* were common in rhizosphere of different Aonla varieties. Maximum total spore count was recorded for *Glomus 1* (234), followed by *Glomus II* (107), *Acaulospora 1* (105), and *Acaulospora II* (52). The poorest spore count was recorded for *Gigaspora* (11). The better counts were recorded during rainy seasons than during drier periods.

Colonization index was significantly superior in upland plants (22.7%) as compared to water logged plants (13.6%). Total spore counts were also more in upland plants (125) than lowland plant (61). The results indicated that *Glomus* species had better adaptability to water logged conditions in Aonla plants than other VAM species.

Results on effect of intercropping on mycorrhization of Aonla showed that colonization index was significantly superior in Aonla plants with wheat (38.4%) than in Aonla plants grown without wheat (24.6%) during crop period. While during pre- crop and post- crop periods, it was at par in both treatments i.e. with (18.7%, 23.7%) and without wheat (20.9%, 24.3%),

respectively. The observed differences can be explained on the basis of better moisture availability in agroforestry plot, as the intercrop was irrigated. The observations on VAM spore count per 100 g soil from rhizosphere of Aonla plants grown with wheat were at par with respective observations on Aonla plants grown without wheat, during all above mentioned crop periods. VAM species composition did not show any qualitative changes, however some quantitative changes in species composition were recorded.

Among different Ber varieties/wild relative maximum colonization index was recorded in Banarsi karaka (32.1%) and Seo (32.1%), followed by Ghot (30.0%), Makor (28.6%), Jharberi (28.1%) and Desi (27.8%). The poorest index value was recorded in Gola (24.3%). However, the difference in the colonization index of different Ber variety/wild relative were non-significant. Maximum VAM spore count was recorded in Banarsi Karaka (29.5 per 100 g soil), followed by Ghot (28.8 per 100 g soil), Gola (25.8 per 100 g soil), Jharberi (22.4 per 100 g soil) and makor (21.0 per 100 g soil). The poorest spore count was recorded in Desi (19.2 per 100 g soil) and Seo (15.3 per 100 g soil). Maximum total spore count was recorded for *Glomus I* (496), followed by *Acaulospora I* (191), *Glomus II* (75), *Acaulospora II* (49) and *Gigaspora* (11). The poorest spore count was recorded for *Glomus mossae* (3).

Differences in colonization index values of Chironji at its two sites i.e. Jakhlon (27.0%) and Nilkanth (18.9%) were non-significant. Maximum total spore count was recorded for *Glomus I* (61), followed by *Glomus II* (29), *Acaulospora I* (4) and *Acaulospora II* (2). The poorest counts were in *Gigaspora* (1) and *Glomus mossae* (1). Total spore counts were 64 and 34 at Nilkhanth and Jakhlon, respectively.

Among Lasoda sites, maximum colonization index was recorded at NRCAF, silvipasture site (32.9%), followed by NRCAF, block plantation and Nareta (16.9). Maximum total spore count was recorded for *Glomus I* (75), followed by, *Glomus II* (36) and *Acaulospora I* (24). Poorest total count was in *Acaulospora II* (1) and *Gigaspora* (1). Among different Lasoda sites,

maximum spore count was in NRCAF, block plantation (77), followed by NRCAF, silvipasture site (60) and in Nareta village (0).

Among different soil types, maximum colonization index was recorded in lateritic soil (27.9%), which was significantly more than colonization in red (21.2%) and black soils (17.9). Maximum total spore count was recorded in lateritic soil (376), followed by black soil (221) and red soil (122).

Six cultures of *Glomus* sp. and one culture of *Acaulospora* were purified from trap cultures set to isolated VAM fungi from rhizosphere of Aonla, Ber, Chironji and Lasoda. These fungi were multiplied on maize roots and utilized in further studies. Characteristics of above mentioned VAM species have been summarized in Table 4.19.

Results on effect of inoculation of different VAM species on growth and P uptake of Aonla showed that shoot length was significantly increased by *Glomus* 1 and *Glomus* 4. Collar diameter was significantly increased by *Glomus* 1. *Glomus* 1, *Glomus* 6, *Glomus* 4 and *Glomus* 3 significantly increased fresh shoot weight, *Glomus* 1, *Glomus* 4, *Acaulospora* 1, *Glomus* 3 and *Glomus* 6 significantly increased dry shoot weight and *Glomus* 1, *Glomus* 6, *Acaulospora* 1, and *Glomus* 3 significantly increased dry root weight. Maximum phosphorus uptake per plant was recorded in *Glomus* 3 (97.197 mg), followed by *Acaulospora* 1 (72.383 mg) and *Glomus* 6 (57.977 mg), which were significantly superior to control. *Glomus* 1 was ranked as most efficient VAM fungi for Aonla, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by *Acaulospora* 1 and *Glomus* 3 (Table 5.3).

In Ber, none of tested VAM fungi increased shoot length and collar diameter of Ber. *Glomus* 1 (48.07 g) and *Glomus* 6 (38.78 g) significantly increased shoot fresh weight. *Glomus* 3 (62.42 g), *Glomus* 4 (59.43 g) and *Glomus* 6 (57.90 g) significantly increased root fresh weight. *Glomus* 1 significantly increased dry shoot weight and *Glomus* 3, *Glomus* 6, *Glomus* 4 (22.37 g) and *Glomus* 1 significantly increased dry root weight. Maximum

phosphorus uptake per plant was recorded in *Glomus* 3 (75.897 mg) followed by *Glomus* 1 (68.507 mg) and *Glomus* 6 (64.537 mg), which were significantly superior to control. *Glomus* 3, *Glomus* 6 and *Glomus* 1 were found superior to other VAM fungi in enhancing seedling dry biomass and P uptake by Ber seedlings (Table 5.3).

Among tested VAM species *Glomus* 4 was found more effective in increasing biomass of Chironji in terms of shoot length, collar diameter, fresh and dry weight of shoot and root, *Glomus* 6, *Glomus* 1 *and Glomus* 3 also increased the shoot length, fresh and dry biomass of the tree species. *Acaulospora* 1 and *Glomus* 5 significantly increased collar diameter but these treatments were at par with control with respect to other tested parameters. *Glomus 2* decreased the growth of Chironji, however the differences were not significant.

Glomus 4 and *Glomus* 5 significantly increased shoot length of Lasoda and no significant differences among different treatments were recorded in collar diameter. *Glomus* 4, *Glomus* 5 and *Glomus* 1 significantly increased fresh shoot weight and no significant difference were recorded in dry shoot weight, *Glomus* 2 and *Glomus* 4 significantly increased fresh root weight, *Glomus* 2, *Glomus* 3, *Glomus* 4 and *Glomus* 1 significantly increased dry root weight and all the treatments significantly increased P uptake per plant. *Glomus* 1 was ranked as most efficient VAM fungi for Lasoda, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by *Glomus* 2 and *Glomus* 4.

Results on build up of VAM mycorrhizal colonization of different crops in different seasons (Rabi, Zaid and Kharif) showed that maize was a good host for isolated *Acaulospora* and *Glomus* species.

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Appendix

Appendix –I

Meteorological data of NRCAF, Jhansi during experimental period

Months	Temperature (^{0}C)		Relative humidity (%)		Rainfall
	Maximum	Minimum	Forenoon	Afternoon	(mm)
July, 2003	34.2	25.4	89	61	192.5
August, 2003	32.6	24.7	94	70	177.0
September, 2003	30.0	23.7	97	78	673.0
October, 2003	33.0	16.3	88	47	000.0
November, 2003	28.9	10.9	88	47	000.0
December, 2003	23.9	8.2	91	51	0.212
January, 2004	19.6	6.3	95.2	56.2	018.0
February, 2004	27.7	8.4	92.5	45.5	000.0
March, 2004	36.7	15.5	72.4	25.6	001.8
April, 2004	39.9	21.2	58.7	26.0	000.0
May, 2004	42.2	27.2	55.2	34.4	001.2
June, 2004	36.7	26.4	75.2	47.2	069.7
July, 2004	28.6	25.6	68.0	54.4	175.4
August, 2004	32.9	24.1	90.2	63.7	151.5
September, 2004	32.1	23.2	90.0	56.7	043.3
October, 2004	31.6	14.9	85.2	40.7	024.4
November, 2004	30.3	10.3	81.2	28.5	001.2
December, 2004	24.0	7.1	85.5	37.7	000.0
January, 2005	21.6	6.2	90.6	45.4	002.04
February, 2005	27.5	9.9	86.0	36.7	002.80
March, 2005	31.1	15.0	76.5	31.2	037.20
April, 2005	38.3	17.5	58.2	24.6	008.20
May, 2005	43.1	24.0	47.2	28.5	000.00
June, 2005	41.7	26.9	60.0	35.2	014.20
July, 2005	32.6	25.2	90.6	68.2	014.60
August, 2005	33.7	24.2	86.7	59.5	082.80
September, 2005	33.3	24.0	90.7	64.5	075.50
October, 2005	34.1	15.5	82.2	30.0	001.80
November, 2005	30.1	10.0	82.2	24.5	000.00
December, 2005	24.0	5.2	90.2	37.2	001.20

January, 2006	24.1	6.2	90.8	39.6	000.0
February, 2006	31.6	11.7	87.3	38.5	000.0
March, 2006	31.8	14.1	84.5	43.0	006.1
April, 2006	40.0	19.4	62.4	25.2	000.2
May, 2006	41.8	25.6	61.6	34.8	013.1
June, 2006	39.0	26.8	68.0	13.3	013.4
July, 2006	32.9	25.7	87.0	67.2	023.7
August, 2006	32.0	24.4	89.5	67.5	023.3
September, 2006	34.8	22.8	86.3	50.5	001.9
October, 2006	34.8	18.0	77.8	35.5	000.0
November, 2006	29.9	11.8	85.3	33.5	000.0
December, 2006	25.6	8.5	84.0	39.3	001.2

Appendix – II

INVAM WORKSHEET

Name _____ Date _____

Slide label information _____

Specimen tentative identification _____

I. Many of these observations can be made with the dissecting microscope but measurements should be made with a compound microscope.

A. Spore color:
   1) In water _____
   2) In mountant _____
   Mountant used: PVL ___ PVLG ___ Other ___

B. Spore diameter: _____ _____

For globose spores: Range _____ um Mean _____ um

For irregularly-shaped spores:
1) Length: Range _____ um Mean _____ um
2) Width: Range _____ um Mean _____ um

C. Composite spore wall thickness (determined on intact spores if possible) _____ um

D. Attachment present? Yes ___ No ___ if no, go to E.
1) Hyphal terminus (= soporiferous saccule) present?
   Yes ___ No ___
2) Bulbous suspensor (= sporogenous cell) present?
   Yes ___ No ___
3) Hypha(e) present ?
   Yes ___ No ___

E. Spore contents:
1) Globular _____ 2) Reticulate _____
3) Granular _____ 4) Other _____

F. Spore with mantle or other surface hyphae? Yes ___No ___
if no, go to G.
   1) Width of hyphae ___ um
   2) Color of hyphae ___
   3) Hyphae sinuous? Yes ___ No ___

G. Spores formed within the roots? Yes ___ No ___

H. Auxiliary cells present? Yes ___No ___
If no go to I
If yes, check which applies:
1) Knobby ___ 2) Digitate ___ 3) Coralloid ___
4) Echinulate ___ 5) Spiny ___ 6) Pigmented ___
If pigmented, indicate color _____

I. Sporocarp present? Yes ___ No ___ if no, go to J .
1) Sporocarp diameter _____
2) Peridium present? Yes ___No ___if yes, indicate color ___

J. Additional comments _____

K. Determine the genus of your specimen
Genus _____ Go to 1, 2, or 3, then II.

1) For *Gigaspora* or *Scutellospora* :
a. Bulbous suspensor (=sporogenous cells) dimensions:
Width _____µm Length _____µm
b. Subtending hyphae (= sporophore hyphae) septate? Yes ___
No___
c. Surface ornamentation on spore present? Yes ___ No___
Description_____
d. Germination shield present? Yes ____No ____

2) For *Acaulospora* or *Entrophospora*:
a. Hyphal terminus (= soporiferous saccule) present?
Yes ____No ____if no, go to II
b. Hyphal terminus collapsed? Yes ____No __if yes, go to II
c. Terminus dimension (diameter or length and width)___µm
d. Description of terminus contents (color; content appearance, e.g., granular, reticulate, globular; texture, e.g., smooth, rough, flaky)_____
_____
e. Hyphal length between spore and terminus _____µm
f. Hyphal diameter at point of spore attachment ____µm
g. Pore diameter on spore at point of attachment _____µm
h. Cicatrix (Hyphal attachment scar) present? Yes ____No ____
If yes, indicate the number present (1 or 2) ____

3. For *Glomus* or *Sclerocystis*

a. Pore occluded? Yes ____No ____

b. Pore diameter _____µm

c. Presence of a septum at the pore? Yes ____No ____If no, go to d.

Protruding septum? Yes ____No ____

d. Hyphal width adjacent to spore wall _____µm

e. Number of attachments per spore _____

f. Outer wall of hyphae contiguous with outer wall of spore? Yes ____No ____

g. Type of attachment: (check all that apply)

(1) straight ___ (2) recurved ___ (3) funnel-shaped ___

(4) branched___ (5) septate ___ (6) constricted ___

(7) swollen ___ (8) other:___

II. Make these observations on broken spores with a compound microscope.

A. Number of wall groups in the spore wall _____

B. Width of each wall group:

A = ___ µm B = ___ µm C = ___ µm D = ___ µm E = ___ µm

C. Number of walls within each group:

A= ___ B= ___ C= ___ D= ___ E= ___

D. Type of wall(s) within each group:

A= Amorphous Wall Group A =

C= Coriaceous

E= Evanescent (ephemeral) B =

L= Laminate

M=Membranous C =

P= Hyphal peridium

U= Unit D =

X= Expanding

E =

Walls ornamented or beaded are indicated by a subscript $_0$ or $_b$ respectively, under the wall type.

Walls difficult to see are shown by * superscript over the wall type.

E. Wall reaction to Meltzer's reagent. Indicate positive (+) or negative (-) for each wall group. If positive, also indicate wall color and wall type affected.

If other reagent or stains are used, record the spore wall reaction as for Meltzer's reagent.

A. _____

B. _____

C. _____

D. _____

E. _____

F. Using the information from section II, construct a murograph.

G. Additional comments: _____

Appendix –III

Hoagland Solution (for plant cultures)

Solution no. 1	**g/L**
KH_2PO_4	0.136
KNO_3	1.02
$Ca(NO_3)_2$	0.492
$MgSO_4.7H_2O$	0.49
Solution no. A	**mg/L**
H_3BO_3	2.86
$MnCl_2.4H_2O$	1.81
$ZnSO_4.7H_2O$	0.22
$CuSO_4.5H2O$	0.08
$H_2MoO_4\ H_2O$	0.09

Solution no. B

Dissolve 26.1g ethylene di-amide tetra-acetic acid in 268 ml of 1 N KOH. Add 24.9g $FeSO_4.7H_2O$ and dilute to one litre. Aerate overnight to produce stable ferric complex. The pH of solution should be about 5.5.

Add 1 ml of solution A to 1 litre solution 1.

Add 1ml of solution B to it. Adjust the pH to 6 with 0.1 N H_2SO_4.

Appendix -IV

Densities of organisms estimated by the dilution method

x	*Two-fold* Number of levels (s)							
	4	5	6	7	8	9	10	11 or more
0.4	.757	.773	.781	.785	.787	.788	.789	.789
0.6	.622	.640	.649	.653	.655	.656	.657	.657
0.8	.537	.556	.566	.571	.573	.574	.575	.575
1.0	.479	.500	.511	.516	.518	.520	.520	.521
1.2	.437	.461	.472	.478	.480	.482	.482	.483
1.4	.406	.432	.444	.450	.453	.455	.456	.456
1.6	.381	.411	.424	.431	.435	.436	.437	.438
1.8	.361	.394	.410	.417	.421	.423	.424	.425
2.0	.344	.382	.399	.408	.412	.414	.415	.416
2.5		.358	.382	.394	.399	.402	.403	.405
3.0			.370	.386	.394	.398	.400	.402
3.5				.379	.390	.396	.399	.401
4.0					.386	.394	.397	.401
4.5						.390	.396	.401
5.0							.394	.401
								.401*
y								
7.0								.399
6.0								.397
5.0							.394	.394
4.5						.390	.390	.390
4.0					.386	.386	.386	.386
3.5				.379	.379	.379	.379	.379
3.0			.370	.370	.370	.370	.370	.370
2.5		.358	.356	.356	.356	.356	.356	.356
2.0	.344	.334	.334	.334	.334	.334	.334	.334
1.8	.327	.323	.323	.323	.323	.323	.323	.323
1.6	.311	.309	.309	.309	.309	.309	.309	.309
1.4	.293	.292	.292	.292	.292	.292	.292	.292
1.2	.271	.271	.271	.271	.271	.271	.271	.271
1.0	.245	.245	.245	.245	.245	.245	.245	.245
0.8	.212	.212	.212	.212	.212	.212	.212	.212
0.6	.167	.167	.167	.167	.167	.167	.167	.167
0.4	.101	.101	.101	.101	.101	.101	.101	.101

Ten fold (Three or more levels)

$x<1$		$x>1, >2$				$y\leq 2$		
x	K	x	K	y	K	y	K	y
		.0	.763	.0	.761	2.0	.744	1.0
		.1	768	.9	.766	.1.9	.744	0.9
		.2	.768	.8	.764	1.8	.734	0.8
		.3	.760	.7	.755	1.7	.712	0.7
0.4	.761	.4	.747	.6	.741	1.6	.684	0.6
0.5	.740	.5	.736	.5	.729	1.5	.658	0.5
0.6	.733	.6	.733	.4	.724	1.4	.638	0.4
0.7	.736	.7	.736	.3	.726	1.3		
0.8	.744	.8	.744	.2	.732	1.2		
0.9	.753	.9	.753	.1	.739	1.1		
1.0	.763	.0	.763	.0	.744	1.0		

When x>1 and y>2 enter the table with the decimal part of x or y only.

Four-fold

x	Number of levels		
	4	5	6 or more
0.4	.704	.706	.707
0.6	.615	.617	.618
0.8	.573	.576	.577
1.0	.555	.558	.559
1.5	.545	.551	.553
2.0	.537	.548	.551
2.5		.545	.552
			.552*
y			
3.5			.550
3.0			.548
2.5		.545	.545
2.0	.537	.537	.537
1.5	.522	.522	.522
1.0	.488	.488	.488
0.8	.464	.464	.464
0.6	.431	.431	.431
0.4	.375	.375	.375

Calculate the mean fertile level x, and the mean sterile level y, where x is the number of fertile plates/number of cultures at each level (n), and x + y is the number of levels. Enter the table with x or y, as indicated, and determine the corresponding value of the tabular entry K. When x and y fall outside the

tabulated range use the value marked with an asterisk (*). The estimate of the number, λ of organisms in the quantity of the medium used for one culture at the highest concentration is then given by log λ = x log *a-K*, where *a* is the dilution factor. The average value of the variance of the mean fertile level is I log 2 /(n log a) and the average value of the variance of log λ is 1/n *(log 2 log a).

Thus:

Two-fold

log λ	=0.30103 *x-K*
V(x)	=1/n
V (log λ)	=0.091/n

Four-fold

log λ	=0.60206 *x-K*
V (x)	=1/2n
V(log λ)	=0.201/n

Ten fold

log λ	=*x-K*
V(x)	=0.301/n

Appendix-V

Soil pH, EC and percent organic content of the soil samples taken from basins of Aonla, Ber, Chironji and Lasoda.

Treatments	pH		EC ($\mu S\ cm^{-1}$)		% OC	
	Mean	Range	Mean	Range	Mean	Range
Aonla (*Emblica officinalis* Gaertn.)						
Varieties						
Chakaiya	5.85	5.39-6.11	43	31-55	1.58	1.34 – 2.22
Kanchan	6.15	5.78-6.45	28	43-52	1.36	0.78-1.91
Krishna	6.08	5.96-6.24	39	28-45	1.18	1.14 – 1.31
NA-7	5.94	5.75-6.12	38	33-49	1.12	0.93 – 1.42
Soil types						
Black soil	5.88	5.26-6.32	49	28-61	1.53	0.78 – 2.74
Lateritic soil	5.93	5.57-6.44	39	33-49	1.19	0.91 – 1.40
Red soil	5.94	5.75-6.12	38	33-49	1.20	1.09 – 1.42
Upland v/s lowland plants						
Waterlogged plants	6.59	6.18-6.86	61	56-66	1.42	0.93 –1.81
Upland plants	6.08	5.96-6.24	39	28-45	1.80	1.39 – 2.17
Agroforesrty						
With wheat	6.34	6.02-6.77	53	45-59	1.42	0.93– 1.81
Without wheat	5.78	5.26-6.1	33	25-42	1.00	0.67 –1.29
Other sites						
Baruasagar, Nagar Palika	7.33	7.15-7.39	231	109-525	2.94	1.71-4.65
Katili	6.29	5.86-6.76	50.25	41-71	1.06	0.62-1.40
Ber (*Zizyphus mauritiana* Lamk.)						
Varieties						
Banarsi karaka	5.94	5.71-6.16	62	26-141	0.91	0.62-1.13
Desi	6.03	5.7-6.24	33	28-41	0.74	0.57-0.93
Gola	6.05	5.78-6.32	31	22-37	1.09	0.88-1.24
Seo	6.09	5.62-6.32	36	29-42	0.76	0.26-1.55
Wild relatives						
Ghot	6.17	5.65-6.8	48	34-57	1.17	0.91-1.60
Jharberi	6.95	6.38-7.86	85	67-99	1.63	0.36-2.79
Makor	6.13	5.66-6.50	44	29-44	1.75	1.39-2.12
Lasoda (*Cordia myxa* Spr.)						
Sites						
Nareta, Datia	7.82	7.64-8.06	133	88-176	0.59	0.65-0.88
NRCAF, Field 1	5.94	5.73-6.09	49	38-56	1.39	1.14-165
NRCAF, Field 2	5.61	5.39-5.77	46	36-53	1.37	1.29-1.55
Chironji (*Buchanania lanzan* Roxb.)						
Sites						
Jakhlon Forest Nursery, Lalitpur	7.0	6.65	68	51-91	1.16	1.03-1.24
Nilkanthh Temple, Lalitpur	6.72	6.38-6.93	60	42-74	1.24	1.03-1.45